Final Report for Ofcom

Competitive models in GPON

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Contents

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1 Executive summary

This is the final report from a study for Ofcom to explore the options for competition on Gigabit Passive Optical Networks (GPONs). Ofcom wishes to understand whether a regulated GPON unbundling requirement would prove effective in supporting competition on GPON fibre-to-the-home (FTTH) networks, such as those being proposed by BT. The study began with a detailed market review of GPON technology developments, and real-life FTTH deployments from around the world.[1] As part of the review, we indentified a number of infrastructure scenarios which support unbundling on GPON. We went on to model the cost of competition[2] and viability of deployment of the most feasible scenarios. The present report sets out the approach, assumptions and results of that cost modelling, and also discusses the prospects for competition and the implications for policy.

It should be noted that **the results produced in this study are indicative**, and are designed only to show the differences between various forms of unbundling. The methodology and results of this study are not intended to inform the setting of prices for either retail or wholesale products.

In the market review, we compared GPON technology to point-to-point (PTP) fibre architectures, and noted that GPONs are not naturally suited to unbundling, due to the shared nature of the network. We also gave a detailed explanation of the expected technological developments, which include longer-range, higher-capacity PONs (10G GPON) and higher-capability PONs using wavelength division multiplexing (WDM). Case studies of FTTH networks from around the world revealed some interesting insights. In France, there is an ongoing debate in the industry between two forms of GPON unbundling; one is suited to the business model of one operator, and the other is suited to a competitor (GPON and PTP deployments). In South Korea, the fact that a high proportion of the population lives in high-density housing has led to extremely low per-household deployment costs (GPON, FTTC, FTTB deployments). In Slovenia, it is an alternative operator that is leading FTTH deployments (all deployments are PTP). In Switzerland, the incumbent is deploying multiple fibres to each home to offer a variety of wholesale access product types (deployments are PTP). In the UK, Ofcom has already published its policy position for FTTH (with a focus on new-build networks), although FTTH deployments are still very limited in scale (GPON and PTP deployments). And finally, in the USA there are only two main deployments of FTTH, and the regulator is relying on cable companies to provide infrastructure competition.

1 See Analysys Mason's report *GPON Market Review: Competitive Models in GPON: Phase 1*, 26 October 2009 (ref: 15340-442)

2 The cost of competition is the additional cost to the consumer arising from there being more than one operator in the market.

Unbundling scenarios modelled

In total we identified nine possible infrastructure topologies that could support competition on GPON networks. In four of these an active electronic interface is used to provide network access, while in the remaining five a passive fibre 'flexipoint' is used to manage connections to parallel competing GPON networks.

Our first active-equipment scenario is based on a layer-2 protocol (e.g. Ethernet) that is used to separate traffic for different users or operators on a single GPON. This scenario is equivalent to the active line access (ALA) concept being proposed by Ofcom, and some 'next generation' bitstream access products being proposed by operators (e.g. BT's GEA). The layer-2 scenario is used as our Base scenario from which to derive the cost of competition, as it requires the least upfront investment (though it offers the lowest scope for innovation by competing operators).

Three other potential active-equipment scenarios based on WDM PONs were considered, with each employing the technology in slightly different ways. The most feasible WDM scenario uses wavelengths to separate *end users* on the PON, with each operator connecting to an assigned transponder on the optical line termination (OLT) cards. This technique is already established in the long-distance and metro markets, and so the scenario is included in the cost modelling. An alternative solution is to use wavelengths to separate *operators* on the PON. This scenario was not modelled, as it would require a proprietary solution and therefore equipment costs are unlikely to reduce to levels viable for the residential market. Finally, we considered a variant of the first WDM scenario, where operators have access to unbundled individual transponders. This scenario was also not modelled as the market is moving towards greater integration of OLT equipment, and therefore a technical solution to support this concept is unlikely to emerge.

For the flexipoint scenarios, we considered locating the flexipoint at three alternative positions: at the cabinet, at the exchange and at the distribution point (DP). With a cabinet location, two flexipoint scenarios were considered: one with a single fibre to the home, and another with multiple fibres to the home. In the single-fibre scenario, the terminating fibre must be changed over at the flexipoint each time a customer churns. The multiple-fibre scenario does not require this (as the customer can swap over their connection in the home), but it does require more fibres in the terminating segment. Both of these scenarios were included in the modelling.

The two scenarios where the flexipoint is located at the exchange echoed the two scenarios with a cabinet location, using either single or multiple terminating fibres. Only the single-fibre scenario was included in the modelling, as the multiple-fibre case would require a large number of fibres all the way from the exchange to the home.

Finally, we included a scenario with the flexipoint at the distribution point and single fibre to the home, in order to test the effect of deploying flexipoints at more disparate locations.

In total, we modelled six unbundling scenarios, which we named as follows:

- Base scenario

- WDM PON
- Field Flexipoint, Single Fibre
- Field Flexipoint, Multi Fibre
- Exchange Flexipoint, Single Fibre
- DP Flexipoint, Single Fibre.

We built an Excel cost model to calculate the cost of competition, and test the economic viability of deployments in these six scenarios, from the point of view of both an incumbent and an altnet. The model was built using a comprehensive set of assumptions agreed with Ofcom, which included coverage and take-up rates, passive network cost elements, active network cost elements, and operating costs. The model also used a geotyping approach which divided the UK into geotypes based on BT exchange areas. In order to represent the deployments that are currently being planned by BT, the model calculated costs for 25% coverage in geotypes representing 66% of the UK. We also modelled the impact on costs of there being more than one operator in the retail market: the presence of more operators leads to a lower utilisation of assets, as the customer base is shared between each of the players.

Results of the cost modelling

Our cost modelling showed that the recovered cost[3] per line per month for the Base scenario is GBP22 for a retail market with three operators. This figure is sensitive to the amount of existing duct that can be reused. The cost per line for 25% coverage ranges from GBP27 per month if 'low' amounts of duct are available, to GBP15 if an operator selectively deploys in available duct. Our result for medium duct availability (GBP22) compares well with BT's proposed pricing for GEA, which is GBP25 per month for a 100Mbit/s peak rate product.[4]

There are significant differences in costs between the unbundling scenarios. If WDM PON is deployed in a retail market with three operators, there is an increase in recovered cost per line per month of GBP12 (53%) over the Base scenario, due to the more expensive equipment associated with WDM technology and the need to manage churn via an Optical Data Frame. This option does, however, give operators more freedom over the bitrates they supply to users and the protocols they use to carry data. This premium of GBP12 would be reduced to GBP7 (32%) if the market were to wait for the technology to mature before deploying it. WDM PON standards are not expected to be finalised before 2013, and the market will need time to adopt the standards and reach volume production of network equipment. Therefore, we do not expect lower-cost 'mature' WDM PON equipment to be available before 2015–2016.

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3 Recovered cost is the amount that needs to be recovered from a customer (plus a margin) in revenue for an operator to maintain a viable NGA business.

4 http://ww.openreach.co.uk/orpg/pricing/loadProductPriceDetails.do?data=Yebin4EnlzheP9l0zYJ%2BMCUycYeyp0LS%2FM7XrdsmaHfgP3UPszSry78iVKC0gUAr

The 'Field Flexipoint, Multi Fibre' scenario with three operators costs GBP5 (23%) per line per month more than the Base scenario. This additional cost is due to the duplication of fibre and sub-duct between the exchange and the flexipoint, and the increased fibre count in the terminating segment between the flexipoint and the home. The 'Field Flexipoint, Single Fibre' scenario with three operators costs GBP11 (48%) more per line per month than the Base scenario. Despite there being only a single fibre per home in the terminating segment, the further increase in cost is driven by the expense of visiting the flexipoint to connect and disconnect customers. In both of these scenarios, operators have even greater control over the services they deliver to end users, including the schedule with which they upgrade the network equipment.

A summary of the additional costs over and above the base case for all unbundling scenarios is given in the table below. (Note that the second WDM PON case (mature technology) is one of our sensitivity tests, and not one of the basic six scenarios.)

Cost differences (recovered cost per line per month, GBP)	*WDM PON (deploy now)*	*WDM PON (mature technology)*	*Field Flexi-point, Single Fibre*	*Field Flexi-point, Multi Fibre*	*Exchange Flexi-point, Single Fibre*	*DP Flexi-point, Single Fibre*
Capex						
Exchange equipment	3.90	1.61	0.62	0.62	0.62	0.62
Flexipoint*	1.41	1.07	1.83	0.75	0.68	18.03
Civils and duct deployment	-	-	-	1.52	1.77	-
Fibre deployment	0.06	0.06	0.20	0.92	1.14	0.26
Sub duct	-	-	0.76	0.76	-	2.36
Customer premises equipment	2.89	0.96	-	-	-	-
Opex						
Flexipoint connection	2.11	2.11	5.81	0.24	1.83	16.75
Exchange power and accommodation	0.96	0.96	0.09	0.09	0.09	0.09
Battery backup	-	-	-	-	-	-
General operating costs	0.40	0.40	0.81	-	0.40	0.81
Additional duct maintenance	-	-	0.67	0.27	0.47	0.67
Internal migration	-	-	-	-	-	-
Total	**11.74**	**7.18**	**10.78**	**5.16**	**7.00**	**39.57**

* Note: for both WDM PON scenarios, 'Flexipoint' costs include both the splitters out in the field and an ODF to manage churn at the exchange

Figure 1.1: Summary of additional recovered costs (GBP) per line per month compared to the Base scenario, in retail market with three operators [Source: Analysys Mason]

The effect of waiting for WDM PON technology to mature can be clearly seen, as the additional costs for exchange equipment, customer premises equipment and splitters in the flexipoint fall if the market waits before deploying WDM PON. For the 'Field Flexipoint, Single Fibre' scenario, the dominant cost is flexipoint connection. There is scope for this cost to fall as we have assumed a scenario in which no two customers join or churn at the same flexipoint on the same day. The additional cost for the 'Field Flexipoint, Multi Fibre' scenario is comparatively low, but this could rise if an engineer is required to visit the home to install line-termination CPE on the correct fibre, if space in footway boxes is lower than expected, or if the operator decides to fully provision flexipoints to pass all homes upfront. Despite requiring an amount of fibre equivalent to a point-to-point network, the additional cost of the 'Exchange Flexipoint, Single Fibre' is less than the 'Field Flexipoint, Single Fibre' scenario because it assumes that the fibre deployment is equally shared between operators, and that no fibre duplication or sub-duct is required. However, this scenario is unlikely to occur in reality as (a) it makes it more challenging for an incumbent to break even (due to the amount of additional duct that needs to be deployed), (b) it could be difficult to arrange the financing for multiple-operator cost sharing, and (c) there may be practical challenges with terminating PTP-like levels of fibre at the exchange. Finally, the reasons for the significant additional cost of the 'DP Flexipoint, Single Fibre' scenario are clear: the disparate flexipoint locations increase the capex of deployment and the opex of connecting users very significantly.

Viability of business cases

We carried out some high-level modelling to give an indication of whether the business case for deploying an unbundled GPON network would be viable for an incumbent and an altnet. We did this by calculating the NPV plus terminal value of cash flows at five and ten years.

It should be noted that the scenarios have been modelled on a standalone basis. We have not considered the implications of a market that contains a mixture of deployments involving active and passive unbundling options. The viability of the business cases described below may be affected if there are competing models of unbundling in the market.

For the active-equipment scenarios (i.e. Base scenario and WDM PON), we assumed that the incumbent would be the only infrastructure operator, and would receive a wholesale revenue per line for giving access to the network. For the Base scenario, the modelling showed that by (a) maximising duct re-use with innovative deployment techniques, (b) selectively deploying in the denser geotypes, (c) using a 100% coverage strategy within those geotypes (as opposed to the 25% used in the default assumptions), and (d) keeping wholesale prices flat, the incumbent should be able to break even at ten years (although not at five years) with 100% of the non-cable wholesale NGA market. Due to the higher cost base, it is more difficult to create a viable case with a WDM PON network, although this could be improved by waiting for the technology to mature.

Under a similar set of conditions (maximising duct re-use, targeting dense geotypes, 100% exchange coverage, and flat retail pricing), the incumbent can also build a positive ten-year business case with some of the flexipoint options if it achieves around a 50% share of the non-cable retail NGA market. This breakeven is possible despite the higher costs of the flexipoint scenarios, as we have assumed that a higher level of revenue could be gained from the sale of retail services. Our modelling showed that altnets could also break even in some flexipoint scenarios and in some geotypes, if they also deployed 100% coverage and achieved a 50–60% retail market share. For both the incumbent and altnet, these levels of market share will be difficult to achieve in the context of the UK's highly competitive broadband market.

Prospects for competition and implications for policy

The prospects for competition based on active-equipment access look good, as the low investment requirements for altnets provide minimal barriers to entry. It will be important to ensure that layer-2 access offers the right functionality and that cost reductions for WDM PON equipment can be achieved. Ofcom could consider facilitating the complete standardisation of fit-for-purpose ALA and residential WDM PON equipment, and promote equipment deployment strategies that allow an efficient upgrade from GPON to WDM. It may be that active infrastructure access will be the only option in some areas, so wholesale prices will require monitoring and potential regulation in future. Ofcom must also consider the cost-benefit trade-off of operators having complete control of line-termination CPE in the home, as this will need to be replaced each time a customer churns.

Managing churn on WDM PON represents a trade-off between cost and maintaining the scope for innovation provided by access to the physical layer. An Ethernet-based solution would lower costs, but reduce innovation to the levels of the Base scenario, and would probably inherit the functionality developed for ALA-type products. Ofcom should monitor the development of ALA to understand whether Ethernet-managed WDM PON can support effective competition. Ofcom should also monitor developments in the FSAN standards for WDM PON.

Furthermore, WDM PON may be deployed as an upgrade to ALA-type GPON[5], and next-generation (10G) GPON is also being developed in parallel to WDM PON. It is unclear at this stage what the most efficient path (balancing cost and ability to compete) will be if the market initially adopts ALA-type GPON and therefore requires an upgrade in 5-10 years time.

We believe that the prospects for competition are more marginal with passive-infrastructure access than with an active-equipment approach, due to higher investment requirements for altnets. The modelling shows that passive-infrastructure-based competition could be achieved in certain geotypes under the right conditions (high duct re-use, wide deployment and inflating prices) and high retail market share. However, unlike the active scenarios – which largely echo the LLU model of interconnection at the exchange – in the passive scenarios there are new planning and operational issues that need to be solved, such as how many parallel networks should be built in the non-shared portion of the network, and the management of shared access to fibre in the terminating portion.

5 Note: our 'mature technology' WDM scenario is modelled on a standalone basis; we have not considered in detail the implications of upgrading from the Base scenario to WDM PON.

Our modelling showed that the cabinet-located flexipoint scenarios are the most viable, with a very small difference in the breakeven tests between the single-fibre and multiple-fibre scenarios. We note that under full infrastructure competition, BT has a significant advantage due to its access to existing duct and fibre infrastructure. The cost-of-competition premium is potentially significant, and we recommend that Ofcom should promote efficient processes to reduce opex costs, and consider shared investment to reduce capex costs. Finally, a flexipoint deployment would require regulated access to terminating fibre and – in the case of the single-fibre scenario – some facilitation of flexipoint standardisation to allow efficient cabinet sharing.

We note that with control over much of the access duct network, BT could take advantage of marginal duct availability, leaving no space for other operators. Therefore, we recommend that Ofcom considers whether it is necessary to promote the efficient use of existing duct space by engaging in the development of innovative techniques and processes enabling duct access. Even so, we note that third-party duct access may not be realistic in some areas, and there are significant operational challenges associated with such access[6]. We also recommend that Ofcom explore in more detail the implications of duct rental, in order to understand how this would improve an incumbent's business case for deploying NGA infrastructure.

In terms of other practicalities, Ofcom should consider whether BT's 'sale and leaseback' agreement with Telereal would adversely impact the use of long-range PONs to deliver NGA services to rural areas.[7]

Due to the importance of take-up levels in the cost-of-competition, we also recommend that Ofcom engages with BT at a detailed business-planning level to understand its projections for the take-up of FTTH. We also recommend engaging with a variety of industry players to fully understand the practicalities of flexipoint operations. Finally, Ofcom may need to consider the impact on the environment of each unbundling option (carbon footprint), as this is likely to vary significantly depending on whether a technician needs to visit a flexipoint to reconnect churning customers.

In summary the study has shown that there are three unbundling scenarios which are worthy of further investigation. These scenarios are highlighted in Figure 1.2 below.

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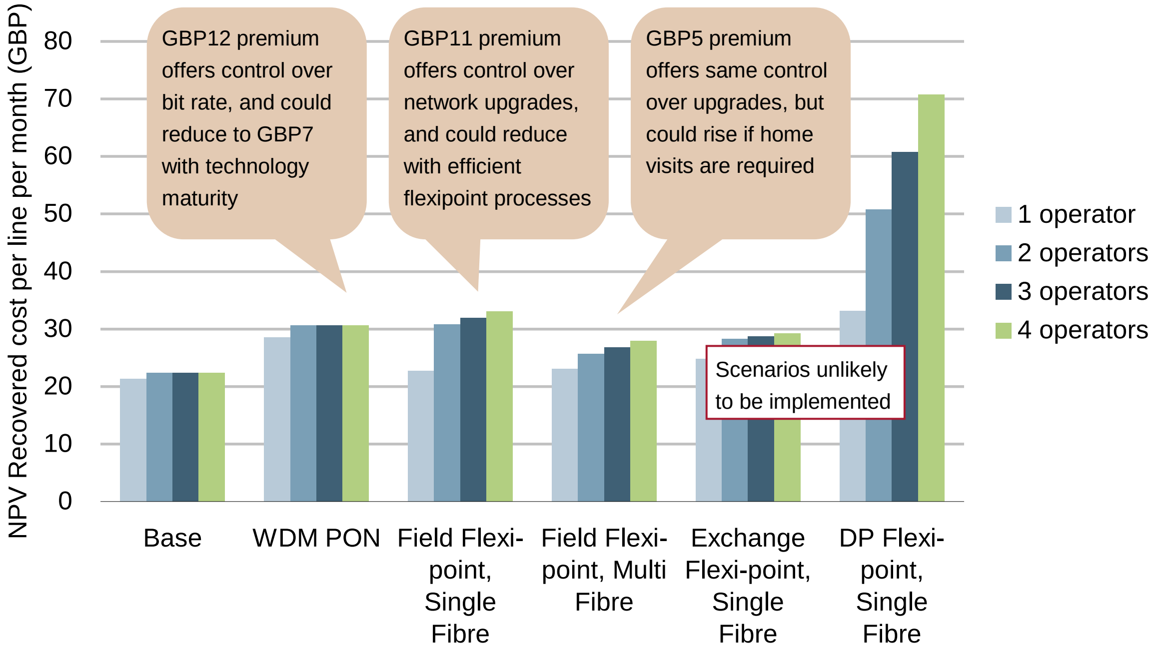
6 See Analysys Mason report for Ofcom "Telecoms infrastructure access – sample survey of duct access", available at www.ofcom.org.uk/telecoms/discussnga/duct/ductreport.pdf

7 Under the terms of the 30-year agreement (signed in 2001), BT may only vacate a certain percentage of properties each year without penalty. See http://www.landsecurities.com/press.asp?PageID=25&MediaID=23&InitialView=False



Note: results for one operator in the unbundling scenarios show the cost of deploying the infrastructure for multiple operators (e.g. flexipoint cabinets) but where only one infrastructure operator is active. In reality, a market scenario with only one active infrastructure operator would be equivalent to the Base scenario.

Figure 1.2: Static cost of competition (2010–2019) under the six scenarios, for a retail market with 1–4 operators [Source: Analysys Mason]

Overall, operators would have to find an additional GBP5–12 a month from their customers to realise the benefits that GPON unbundling offers over an active ALA-type product[8]. The exact nature of ALA-type products will be important for the development of the NGA market, as the scope for innovation they offer will influence an operator's decision as to whether a deeper level of unbundling is required in order for it to compete. It is very likely, however, that in the longer term ALA-type products will be required in some (more rural) geotypes.

[8] The additional GBP5-12 refers to the increase in cost that must be recovered from each customer each month for an operator to maintain a viable business with these NGA unbundling scenarios.

2 Introduction

This report is the final deliverable from a project for Ofcom by Analysys Mason to understand the possibilities for unbundling of GPONs and any associated costs of competition. The project has been delivered with a combination of desk research, modelling and interviews with industry players. This report presents documentation and results for the cost modelling of different options for unbundling of GPONs, and also includes discussion of the regulatory implications of the different unbundling options.

Passive optical networks are being deployed by a number of operators in the UK, and Ofcom must therefore consider policy implications for ensuring competition on such networks. Although GPONs are not naturally suited to unbundling due to the sharing of fibre between multiple end users, options do exist for supporting competition on such networks. These options include separating data from different operators and users by electronic methods (such as division of wavelengths), and using fibre 'flexipoints' to manually connect end users to the PONs of different operators. We have considered six unbundling scenarios in our cost modelling, and these are described below.

Note: the example fibre counts in the diagrams are for three operators serving 64 homes.

- **Base Scenario** – alternative operators access the GPON via a purely active interface, and operators and their end users are separated by layer-2 protocols (e.g. Ethernet packets).

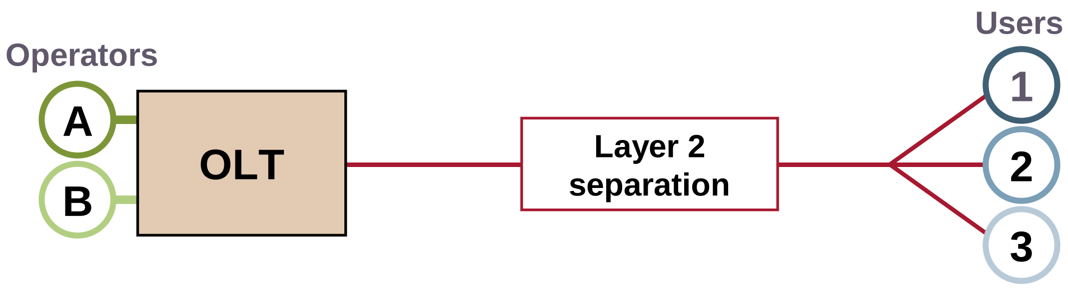


Figure 2.1: Base scenario: layer-2 active access [Source: Analysys Mason]

- **WDM PON** – similar to the Base scenario, except that wavelength division multiplexing (WDM) is used to separate end users. This gives operators a greater degree of control over the capacity delivered to the end user, when compared to the Base scenario.

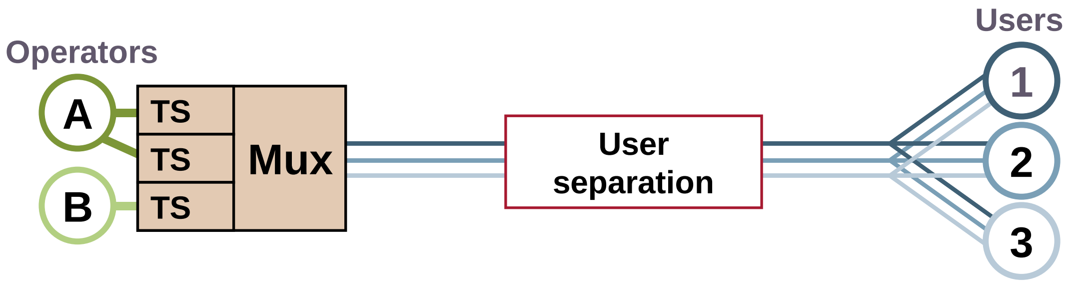


Figure 2.2: *WDM PON scenario: WDM used to separate users; wavelengths assigned [Source: Analysys Mason]*

- **Field Flexipoint, Single Fibre** – each operator deploys its own GPON network between the exchange and a flexipoint in the field (assumed to be at the current cabinet location). A single fibre is installed between the flexipoint and the home, and when a customer churns, an engineer must visit the flexipoint to swap the terminating fibre onto the new operator's GPON.

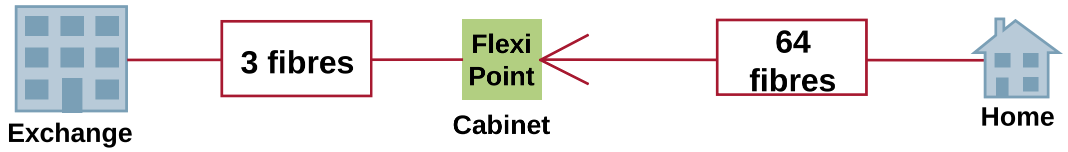


Figure 2.3: *Flexipoint in the field (cabinet); single fibre per home [Source: Analysys Mason]*

- **Field Flexipoint, Multi Fibre** – similar to the previous scenario, except that multiple fibres are laid in the terminating segment between the flexipoint and the home. This means that when a customer churns, they just move their equipment onto a different fibre within the home.

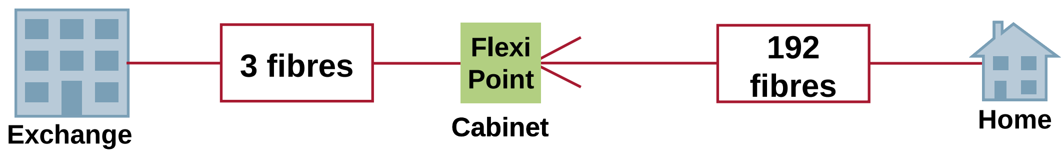


Figure 2.4: *Flexipoint in the field (cabinet); multiple fibre per home [Source: Analysys Mason]*

- **Exchange Flexipoint, Single Fibre** – again similar to the second scenario, except that the flexipoint is located in the exchange. This has the advantage that the location that must be visited when a customer churns is more centralised, but requires point-to-point levels of fibre between the exchange and the home.

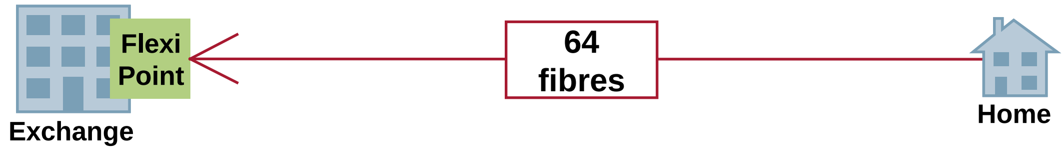


Figure 2.5: Flexipoint in the exchange; single fibre per home [Source: Analysys Mason]

- **DP Flexipoint, Single Fibre** – again similar to the second scenario, except that the flexipoint is located in the distribution point (DP). In this scenario, the cost of the individual flexipoint is lower (due to there being fewer lines at each flexipoint), but this is offset by the large number of flexipoints.

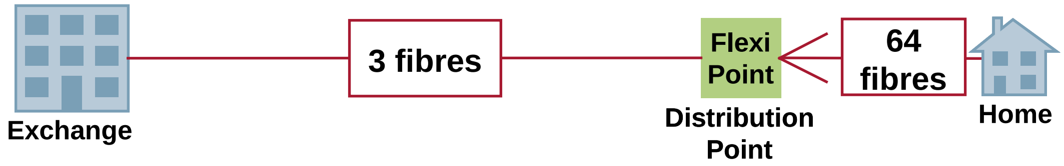


Figure 2.6: Flexipoint at the distribution point; single fibre per home [Source: Analysys Mason]

Three other scenarios were also considered in the early stages of the study, but these were not chosen for detailed modelling as they were thought to have a low level of feasibility. An 'Exchange Flexipoint, Multiple Fibre' scenario was not modelled as it would require large amounts of fibre across the access network, even greater than a point-to-point deployment. A WDM scenario which uses WDM to separate operators instead of users, was not modelled as the architecture would require a proprietary solution. Finally, a WDM scenario in which the individual transponders are unbundled (separately from the multiplexor) was not modelled, as we believe that OLT technology will become increasingly more integrated and therefore this solution is unlikely to be developed by the industry.

Ofcom wishes to understand what additional costs are incurred by the consumer when competition is based on the above architectures. It also wants to understand what is the financial viability of deploying such architectures, from the point of view of both an incumbent and an altnet. Finally, Ofcom wishes to understand how the cost of competition[9] and financial viability are affected by various practical constraints and deployment strategies, such as duct availability and the size of roll-out.

Having defined the scenarios to be considered, this study used a Microsoft Excel model to calculate the costs and estimate the financial viability for each scenario. This report describes this

[9] The cost of competition is the additional cost to the consumer arising from there being more than one operator in the market.

model, presents its results, and discusses their implications for regulatory policy. The report is structured as follows:

- Section 3 sets out the network cost assumptions.
- Section 4 presents the results of the cost modelling in the form of charts which set out the deployment and operating costs of the various unbundling options. We also present estimations of the financial viability of such deployments.
- Section 5 discusses the implications of the results, including the prospects for competition, steps to avoid market foreclosure, and recommendations for regulatory policy.

Annexes to the report describe the calculation flow of the model and explain our approach to geotyping the UK population.

Note: This report should be read in conjunction with our deliverable from Phase 1 of the study, which reviewed the current market for GPONs.[10]

[10] *GPON Market Review: Competitive Models in GPON* , 26 October 2009 (ref: 15340-442).

3 Network cost assumptions

The network cost assumptions are grouped under five headings: global assumptions, passive equipment costs, active equipment costs, opex costs and scenario parameters. The individual assumptions are explained in more detail in this section. Many of these assumptions vary according to the part of the network being considered. We break the access network down into six sections (A–F), as shown in Figure 3.1.

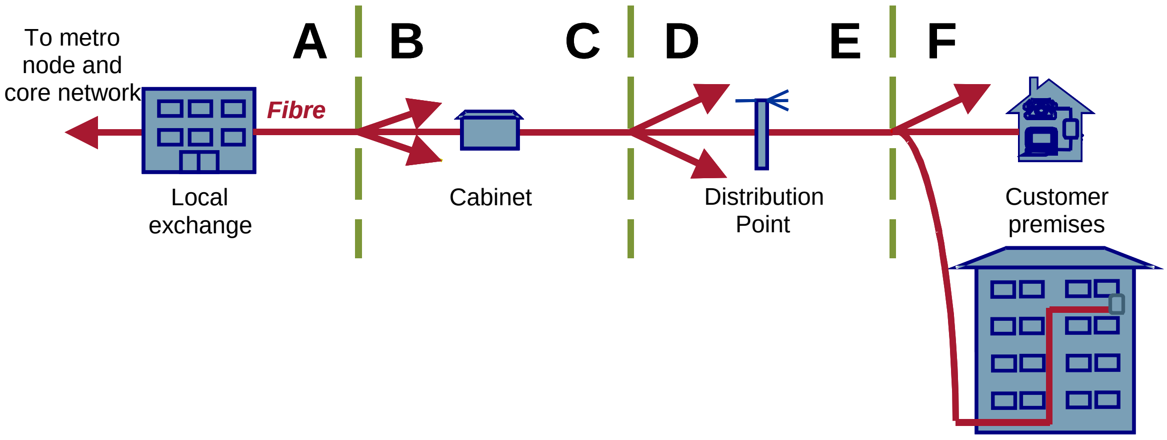


Figure 3.1: Access network broken down into six sections (A-F) [Source: Analysys Mason]

Many of the cost inputs are based on Analysys Mason's previous modelling experience with the Broadband Stakeholder Group (BSG) and broadband operators.[11] Where necessary, we have included new assumptions, and these are described below.

3.1 Global assumptions

Number of operators

We also modelled the impact on costs of there being more than one operator in the retail market. The presence of more operators leads to a lower utilisation of assets, as the customer base is shared between each of the players. We have assumed that the NGA market always includes an incumbent (i.e. if there is only one player, this is the incumbent), but can also include a number of alternative operators. We have considered the cost of competition with two, three and four operators.

11 Analysys Mason report for BSG, 'The costs of deploying fibre-based next generation infrastructure', available at http://www.broadbanduk.org/component/option,com_docman/task,doc_download/gid,1036/

FTTP coverage and roll-out

We have assumed that GPON fibre to the premises (FTTP) will be rolled out to cover 25% of homes in each geotype. We have also considered extending that roll-out to up to 100% of each geotype. We have assumed a network roll-out over four years (2010–2013).

Broadband penetration and NGA take-up

We have assumed that of the homes covered by FTTP, 80% will take broadband services. We have further assumed that of those broadband customers, take-up of NGA services will rise from 30% in 2010 to 49% in 2019. This increase in take-up is assumed to represent net additions (including the effects of churn).

Cable market share

We have assumed that cable has a constant retail market share of 35% within coverage areas. Note: cable coverage areas vary by geotype.

Churn

We have assumed a constant churn rate of 20% (i.e. on average each customer churns every five years).

Revenue per user

For the breakeven analysis in the flexipoint scenarios, we have assumed that each user of NGA services provides GBP540 in retail revenue per year (equivalent to GBP45 per month). This is based on current industry benchmarks for a multi-play broadband service. We have assumed that this revenue remains flat in nominal terms over the forecast period.

For the base and WDM PON scenarios, we have assumed that the infrastructure operator (incumbent) initially receives a wholesale revenue of GBP300 per line per year (GBP25 per month). This is based on current prices for the FTTP GEA product. We have assumed that this revenue falls to GBP20 per line per month over the forecast period due to competition (e.g. from cable).

We have also modelled the case where wholesale revenue is initially pegged to current wholesale charges, but then delivers a premium over time. In this case, we assume that wholesale revenue is GBP15 per line per month initially, rising to GBP20 per month at the end of the forecast period. This case is designed to model an environment where the infrastructure operator is able, over time, to extract additional value over and above that of ‘basic’ access.

WACC

To calculate the net present value and terminal value for the breakeven analysis, we have assumed a weighted average cost of capital (WACC) of 12%. The is appropriate for a European broadband operator.

Inflation

We have used data from the Economist Intelligence Unit (EIU) for average yearly inflation on a historical and forecast basis.

Depreciation periods

In order to calculate the cost of competition, we have assumed a depreciation period for each asset class. These are based on the periods used

3.2 Passive equipment costs

Fibre

The cost and diameter of fibre cable increase with the number of fibres. We have assumed that cable reaches a price and size minimum at eight fibres: i.e. the costs and diameters for two, four and eight fibres are assumed to be the same. Fibre costs fall at 5% per year in real[12] terms due to increasing economies of scale (an assumption based on interviews with operators). Please see the model for more detail. We have also assumed that each operator deploys sufficient fibre in shared parts of the network (i.e. up to the flexipoint) to pass all homes within a deployment area. Competition therefore creates some duplication of fibre, in the part of the network between the exchange and the flexipoint.

Duct re-use

The model allows the proportions of duct that can be re-used in each section of the network to be varied, according to the following assumptions:

Duct reuse	*% of duct reusable (A-B)*	*% of duct reusable (C-D)*	*% of duct reusable (E-F)*
High	95%	70%	60%
Medium	80%	50%	30%
Low	50%	25%	15%
Selective deployment	95%	95%	95%

Figure 3.3: Duct reuse sensitivities [Source: Analysys Mason]

The amount of duct available for re-use (i.e. sufficient duct space to avoid civil works) varies in two of the unbundling scenarios. This is based on the assumptions agreed for our BSG modelling work for the deployment of a point-to-point network. Note: the assumptions given in the table below are additional adjustments to the duct availability assumptions listed above. to calculate the cost of competition, we assume that the incumbent incurs all the costs of deploying new duct.

	Duct re-use adjustment relative to base case		
Scenario	*Section A-B*	*Section C-D*	*Section E-F*
Field Flexipoint, Multi Fibre to Home	100% (no adjustment)	80%	100% (no adjustment)
Exchange	88%	80%	100% (no

12 Note: real price changes are added to inflation to give nominal price inputs to the model.

analysys mason

Flexipoint, Single Fibre to Home	adjustment)

Figure 3.4: Duct re-use adjustment by scenario [Source: Analysys Mason]

Duct deployment, including civil works

We have assumed that duct deployment (including civil works) varies according to the terrain of deployment: road, footpath, grass verge, aerial, or direct burial (final drop only). The proportion of each terrain varies by geotype. We assume that the cost per metre of the duct is approximately constant, and that costs are dominated by civil works. Duct deployment costs by terrain are shown in Figure 3.5. These costs rise with inflation.

Terrain	*Duct deployment per metre (GBP)*
Road	100
Footpath	60
Grass verge	40

Figure 3.5: Duct deployment costs [Source: Analysys Mason]

Sub-duct deployment

Where more than one operator is deploying fibre, we have assumed that sub-duct must be deployed. We assume a uniform cost of GBP1 per metre for sub-duct materials, and GBP3 per metre for sub-duct installation. We have further assumed that sub-duct installation costs are only incurred when installing sub-duct in existing duct – i.e. operators can insert sub-duct into new duct *before* it is deployed at zero additional cost. Sub-duct is only deployed in parts of the network where fibre from more than one operator shares existing duct, i.e. up to the flexipoint. Cost estimates are based on industry benchmarks. Sub-duct costs rise with inflation.

Cable installation

We have assumed that installing fibre cable both aerially and in ducts costs GBP8 per metre. This cost rises with inflation. We assume that the proportion of the E-F section of the network which is aerial varies by geotype (see Figure 3.1 above for network description).

Geotype	*Fraction of E-F aerially*
London	1%
>500k pop	5%
>200k pop	10%
>20k lines (a)	15%
>20k lines (b)	20%
>10k lines (a)	20%
>10k lines (b)	20%

Figure 3.6: Fraction of aerial in E-F section of network [Source: Analysys Mason]

Fixed cost per final drop per visit — We have assumed that the final drop to a house (Section F in Figure 3.1 above) is only connected when a customer takes a service. We have assumed this costs GBP100 per customer visit for most scenarios. This cost rises to GBP150 for the 'Multi-fibre to the home' scenario, to take into account the additional cost of connecting up more fibres. These costs rise with inflation.

Multi-dwelling unit in-building wiring — We have divided the cost of in-building wiring for multi-dwelling units into vertical and horizontal components. We have assumed that the vertical component is incurred as part of network deployment (in order to 'pass' a home). The horizontal component is only incurred when the customer takes the service (akin to final drop above). We have assumed that the horizontal cost is again GBP100 for most scenarios, and GBP150 for the 'multi-fibre' scenario. These costs rise with inflation.

Splitters and network split ratios — We have assumed that splitters and network split ratios are different for GPON and WDM PON technology.[13] For GPON the maximum split ratio of the network (max users per shared fibre) is 64, while for WDM PON it is 32. The split ratios of individual splitters is assumed to be 8 for GPON and 32 for WDM PON (two levels of splitter are therefore assumed for GPON). We have assumed splitter unit costs of GBP70 for GPON and GBP1000 for WDM (the WDM splitter is an arrayed waveguide grating). We have assumed that GPON splitter costs fall at 5% per year in real terms due to economies of scale. WDM PON splitter costs fall at 20% per year in real terms, in line with the costs of optical line termination equipment (see below).

In the base, WDM PON and 'Field Flexipoint, Multi Fibre' scenarios, we have assumed that each operator deploys enough splitters up front to allow for growth in its customer base as the take-up of NGA services increases (within a given retail market share). In the 'Field Flexipoint, Single Fibre', 'Exchange Flexipoint, Single Fibre' and 'DP Flexipoint, Single Fibre' scenarios, we have assumed that splitters are deployed incrementally as the subscriber base grows.

Optical distribution frame (ODF) — Our assumptions for the costs and fibre capacities of ODFs are based on information from Tyco Electronics. A 'connectorised' shelf ODF is needed for switching users to a different operator in the 'single fibre per home' scenarios with flexipoints at the cabinet (field) and exchange (note we have assumed that an ODF is required at the exchange to manage churn in the WDM PON scenario). This ODF holds 192 fibres and costs GBP2100. A boxed ODF, to allow switching at the DP (in the 'DP Flexipoint, Single

13 GPON is assumed to be deployed in all scenarios except the WDM PON scenario.

Fibre' scenario), holds 48 fibres and costs GBP800. All costs are assumed to fall at 5% per year in real terms as economies of scale are achieved.

Flexipoint accommodation

Costs and capacities for accommodation of ODFs are also based on information from Tyco Electronics. A field cabinet accommodates three shelf ODFs and costs GBP3000 (GBP1000 cabinet cost, plus GBP2000 to install and commission). An exchange cabinet to house the shelf ODFs can hold 14 ODFs, and costs GBP2400 (GBP1400 cost, plus GBP1000 for installation and commissioning).

For the 'multi-fibre to the home' scenario, we have assumed that flexipoints (splitters and fibre) could be accommodated in existing footway boxes. However, we assume that 10% of footway boxes would require an upgrade for this task, at a cost of GBP2000 per box.

All costs fall at 5% per year in real terms as economies of scale are achieved.

3.3 Active equipment costs

Optical line termination (OLT)

For OLT costs we have again assumed differences between GPON and WDM PON. Each GPON card supports 640 users (10 ports at 64 users per port) and costs GBP25 000 per card (GBP39 per user). Each WDM PON card support 32 users (32 ports at 1 user per port) and costs GBP10 000 (GBP313 per user). The cost of GPON equipment costs falls at 10% per year in real terms. We assume that the cost of WDM PON equipment will fall to the same price per user as PTP in ten years, and have therefore included a 20% per year real price reduction. WDM PON costs are based on interviews with operators.

Aggregation switch

We have included the cost of a switch to aggregate traffic from each OLT card in the exchange. Due to the low number of subscribers assumed in this study (as roll-out only may only extend to 25% of homes), we have included the cost of *part* of a switch: we assume that the GPON cards could share switches with other technologies present at the exchange.[14]

We have assumed that each GPON OLT will perform some statistical multiplexing, and therefore we have assumed that each OLT card will require 10Gbit/s of switch capacity. In the case of WDM PON, we assume that all statistical multiplexing is performed in the switch itself.[15] We have assumed that the cost of 10Gbit/s switch capacity is GBP2500 (based on an

14 We also carried out a sensitivity test assuming 100% coverage, and verified that the costs scale correctly.

15 Note: WDM PON OLT card supports 32 users; GPON OLT card supports 640 users

estimate of GBP100 000 for a 400Gbit/s 40-port switch), and that this price falls at 10% per annum in real terms.

Customer premises equipment (CPE)

We have assumed that GPON line-termination CPE costs GBP80 per unit, falling at 10% per year in real terms. We assume that WDM PON line-termination CPE will initially cost GBP300 per unit (estimated based on a 10% reduction in the current cost of business CPE), falling to a price 70% more expensive than GPON over ten years. We have therefore assumed a 17.5% per year price reduction in real terms. WDM PON costs are based on interviews with operators.

Battery backup

We have assumed an additional cost for battery backup of GBP100 per home, which falls at 10% per year in real terms.

3.4 Operating costs

Flexipoint connection

We have assumed two components to the cost of connecting users at the flexipoint, upon both initial customer connection and churn.

For flexipoints in the field there is a fixed cost of GBP250 per operator to visit the flexipoint, while for flexipoints in the exchange this cost is GBP75. These assumptions are based on the difference between Openreach’s prices for transfer connections on SLU and LLU. We assume that during roll-out, each flexipoint is visited only once and all new customers are connected at that time. For new connections after roll-out, and for visits due to churners, we assume that no two customers will connect or churn at the same flexipoint on the same day. Although this is a likely scenario, it may be possible for operators to schedule a number of flexipoint visits together to reduce costs, especially as customer numbers grow.

The cost per user is GBP12 for most scenarios, but GBP18 for the ‘multi-fibre’ scenario as fibre splicing is then required (which is more complicated than swapping connectors). These costs are Analysys Mason estimates (based on industry benchmarks) and are assumed to rise with inflation. In all scenarios, we have assumed that flexipoint connections are made as users take up NGA services, rather than connecting all homes in a coverage area up-front.

In the WDM PON scenario, we have assumed that churn is managed via an ODF in the exchange. Therefore this scenario includes initial connection costs at the splitter location in the field and the ODF location in the exchange, and ongoing connection costs at the exchange to manage churn.

Internal migration costs

We have assumed an internal migration cost which is incurred in all scenarios when a customer migrates or churns. This cost is due to internal activities such activating/deactivating ports on line cards, and swapping customer records. Using Openreach's charges for migrations on IPStream and DataStream as a guide, we assume this cost is GBP10 (rising with inflation).

Other operating costs

We have estimated other operating costs on a per-line basis, based on the costs of operating a copper network as published in the BT regulatory accounts. We have adjusted the costs to represent what is expected for fibre, using the factors shown in the table below.

Operating cost	*Adjustment (copper to fibre)*
Network support	-50%
General support	-20%
General management	-10%
Finance and billing	0% (no adjustment)
Bad debts	0% (no adjustment)
Other Costs	0% (no adjustment)

Figure 3.7: Operating cost adjustments [Source: Analysys Mason]

In the case of provision/maintenance costs, we believe that any newly built fibre-based network should offer very substantial savings in maintenance costs over legacy copper networks. However, we also recognise that the use of connectors at flexipoints to manage churn will increase maintenance costs, due to the risk of error from the manual intervention. We believe that this will have a greater effect at flexipoints out in the field than it will with those in the exchange. In the absence of operational data on the maintenance of unbundled fibre networks, we have assumed the following reductions in the per-line provision/maintenance costs from copper to fibre.

Scenario	*Adjustment (copper to fibre)*
Base	-80%
Field Flexi-point, Single Fibre	-50%
Field Flexi-point, Multi Fibre	-80%
Exchange Flexi-point, Single Fibre	-65%
WDM PON	-65%
DP Flexi-point, Single Fibre	-50%

Figure 3.8: Provision/maintenance cost adjustments [Source: Analysys Mason]

Additional duct maintenance costs We have assumed additional maintenance costs are incurred by the incumbent if it opens its duct network for use by altnets. In the absence of any data on the maintenance requirements for allowing duct access, we have doubled the existing per-line network maintenance costs as a conservative estimate.

Power We have estimated the power consumption per port of GPON and WDM PON OLTs based on industry data (assuming the WDM PON consumes a similar power per port to PTP). We have then assumed two components to the power charge:

- a variable per-KWh charge, based on the rate supplied to large companies (estimated to be GBP0.08 per KWh).
- a fixed cost per KW of GBP113 per KW, based on Openreach's charges for renting power at the exchange.

These costs rise with inflation. Note: we assume that each OLT card consumes power for all ports, regardless of the number of users on the card.

Accommodation for equipment in the exchange We have estimated accommodation costs based on the per-line costs for the existing copper network. We assume that WDM PON has a similar per-line (per-user) density to PTP, which in turn has a similar density to copper. Costs for GPON are estimated based on the relative user densities between GPON and WDM PON (12 160 users per rack for GPON, and 1024 users per rack for WDM PON).[16] These costs increase with inflation.

Battery backup maintenance Although not requiring replacement with churn (see below), we have assumed that the battery backup at each home must be refreshed every five years. We assume a materials cost of GBP50 (decreasing at 10% per year in real terms), and a labour cost of GBP25 per visit (increasing with inflation).

Duct rental Where an altnet must rent access to the incumbent's duct, we have assumed a rental charge of GBP1 per cm^2 per metre per year, based on the offer from France Telecom. This charge rises with inflation. Where sub-duct is deployed, we have assumed the cable diameter is increased by a factor of 1.6 to account for the area taken up by the sub-duct. This factor is based on our experience of working with operators.

16 GPON: 19 OLT cards per rack, 640 users per card. WDM PON: 32 OLT cards per rack, 32 users per card.

3.5 Control of sensitivities

The model includes switches to activate various sensitivities to test the effect on the results of a number of key factors. Results for the different scenarios are produced automatically by the Excel TABLE() function, as described above. The sensitivities are as follows:

Presence of FTTC We have considered the effects of GPON deployment in the context of a concurrent fibre to the cabinet (FTTC) deployment. We have assumed that in the presence of FTTC, the costs of deploying new duct (including duct and civil works) are shared between the FTTC and GPON deployments in the first two sections of the network (A–B). The sharing of costs is assumed to be equal to the proportion of homes covered, i.e. GPON accounts for 25% of the costs as GPON is planned to cover 25% of households.

The default case is to assume that FTTC will *not* be present. The model allows this assumption to be reversed, to test the impact of sharing duct costs across a dual GPON/FTTC deployment.

Split ratio The model allows the split ratio of the network to be doubled from the base case. This affects the overall split ratio of the network (i.e. the number of users that can be supported on each OLT port and shared fibre) and the split ratio of individual splitters. The unit cost of each splitter remains the same (assuming an increase in capability for no additional cost).

NGA take-up The take-up of NGA services can be varied according to four scenarios: low, medium, high and a scenario where there is a step change in take-up after five years. The profiles of these scenarios are shown in Figure 3.9 below. We have assumed that all migration to NGA services will be incremental (rather than on a mass basis) due to the limited roll-out being modelled.

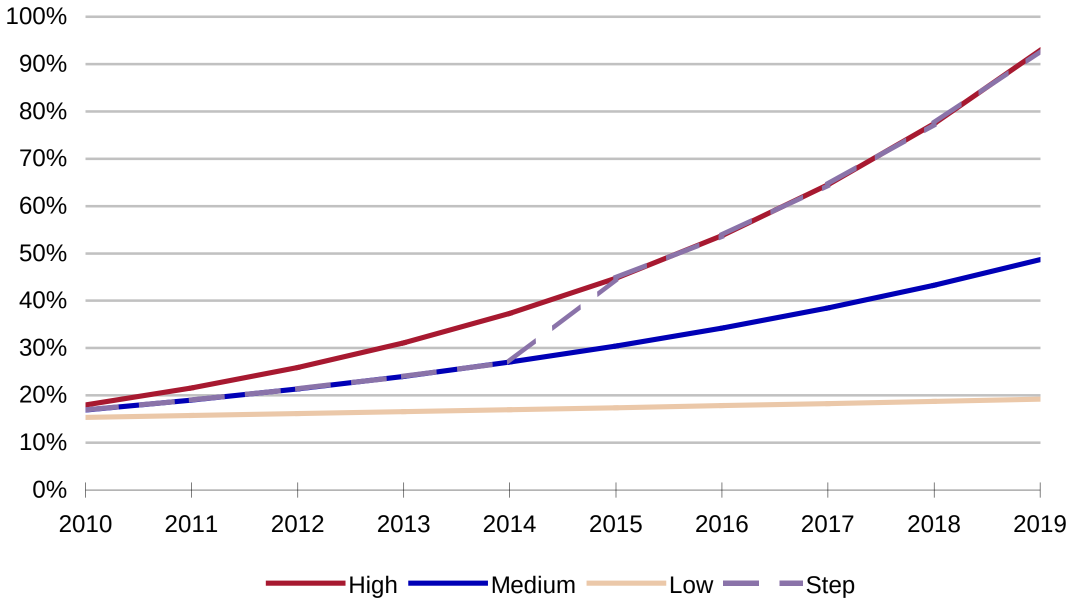


Figure 3.9: Scenarios for take-up of NGA services [Source: Analysys Mason]

CPE replacement We have assumed that the line-termination CPE must be replaced each time a customer churns. This is equivalent to a 'wires-only' approach, where each operator supplies its own CPE. The cost model allows this assumption to be turned off so that CPE costs are only incurred when a customer first takes up a service.

Timing of WDM deployment By default, the model assumes that WDM PON starts to be deployed in 2010. Although we have assumed a significant reduction in WDM PON equipment costs over the forecast period, much of the deployment is done early on, before much of the cost reduction has occurred. Therefore, the model also allows the costs of WDM PON equipment to be set to the lowest price point in the default assumption set (i.e. at 2019) for the entire forecast period. This sensitivity is designed to represent a scenario where the market waits for prices to fall before deploying WDM.

Note: we have assumed that the price of a WDM splitter (arrayed waveguide grating) never falls below 1.5 times the price of a GPON splitter, on a per-line basis. This is due to the higher cost materials required for the WDM splitter.

Breakeven controls The model can be set to model the breakeven times for deployments by either an incumbent or an altnet. Certain costs are included and others are excluded for these two types of operator, as shown in Figure 3.10 below.

Cost	*Incumbent*	*Altnet*
Duct deployment	Included	Not included
Rental of used duct	Not included	Included
Additional duct maintenance costs for having more than one operator use ducts	Included	Not included

Figure 3.10: Incumbent and altnet cost items [Source: Analysys Mason]

3.6 Additional sensitivities in the model

The cost model includes some additional functionality to carry out sensitivity analyses which are not discussed in this study as they are not of immediate concern. They are included as they may become useful to Ofcom in the future.

Battery backup costs

We have assumed that battery backup costs are included in the costs of deployment (both for initial connection and replacement after five years). The model allows this assumption to be turned off, so that no battery backup costs are incurred by any operator. Note: in all cases, we assume that battery backup remains compatible with all line-termination CPE, and does not require replacing when a customer churns.

Sharing of duct costs

To calculate the cost of competition, we have assumed that the incumbent pays for all deployment of new duct. The model allows this cost to be shared between the incumbent and any altnets who are also deploying.

4 Results

4.1 Introduction

In this section we present the results of the cost modelling of different options for unbundling of GPONs. The cost model has the capability to test a wide range of scenarios and sensitivities, and we have provided a broad selection of the possible outputs in this report.

All the cost results are discounted to give their present value in 2009 terms. A discount rate of 12% is used, which is typical for a telecoms operator in Western Europe.

Unless otherwise stated, the results presented here use the following set of core assumptions:

- Three operators: one incumbent and two altnets
- FTTC is not present (duct costs in A-B section of network are fully attributed to the GPON deployment)
- CPE requires replacing on churn
- Duct reuse: 80% (A-B), 50% (C-D), 30% (E-F)
- Four-year roll-out
- Roll-out to: 66% of UK > 25% of homes > 80% broadband penetration > 35% cable share
- NGA take-up: 15% to 49% over ten years
- Churn: 20%.

4.2 Total capex

The **total capex** for the six roll-out scenarios is shown in Figure 4.1 below. Capex is shown for the period 2010–2019, covering initial deployment and the first ten years of operational capex (e.g. replacement of CPE with churn, and installation of additional OLTs as subscriber numbers grow). Results are shown for three operators (one incumbent and two altnets), each deploying a network.

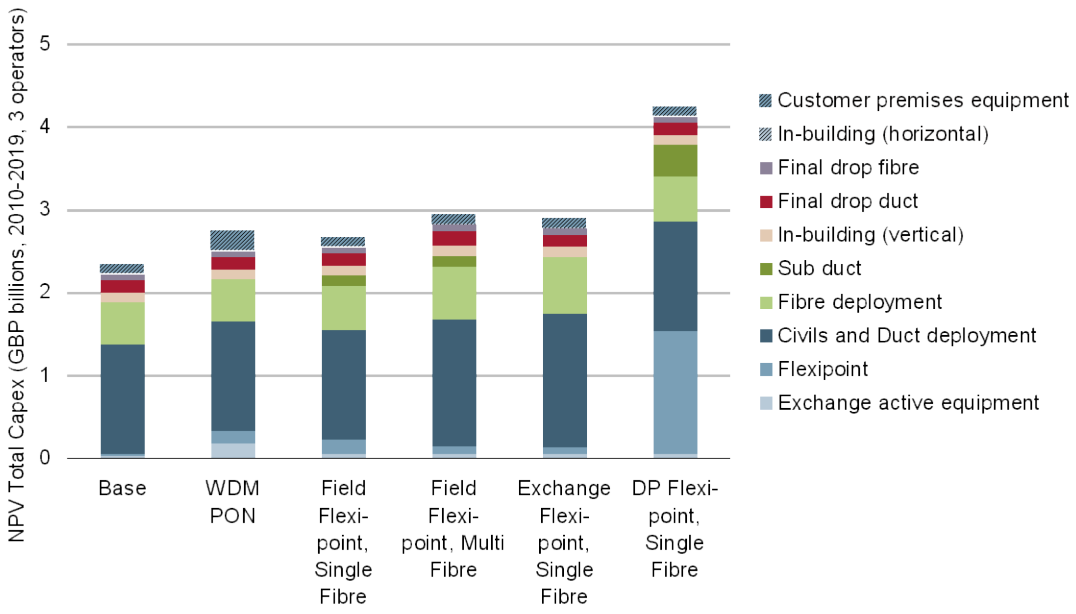


Figure 4.1: Breakdown of total capex (2010–2019) under the six scenarios [Source: Analysys Mason]

Duct and fibre deployment dominate capex costs, comprising 78% of costs in the Base scenario. However, the deployment of parallel fibre networks creates additional cost in the scenarios which include a flexipoint: fibre deployment is GBP0.5 billion in the base case, but this rises to GBP0.7 billion for the scenario where the flexipoint is located in the exchange. We have also assumed that the deployment of parallel fibre requires the installation of sub-duct, which adds further costs of between GBP0.1 billion and GBP0.4 billion in those flexipoint scenarios where parallel networks share duct.

The variation of total capex by geotype is shown in Figure 4.2 below. It can be seen that despite having relatively small proportions of homes, the 'b' geotypes make up a significant proportion of the total cost due to their longer line lengths (which increases duct and fibre deployment costs). However, the effect of longer line lengths on the per-line costs is mitigated by a lower cable coverage in 'b' geotypes: because cable has a lower retail market share in these geotypes, there are proportionately more non-cable NGA users across which to share common costs.

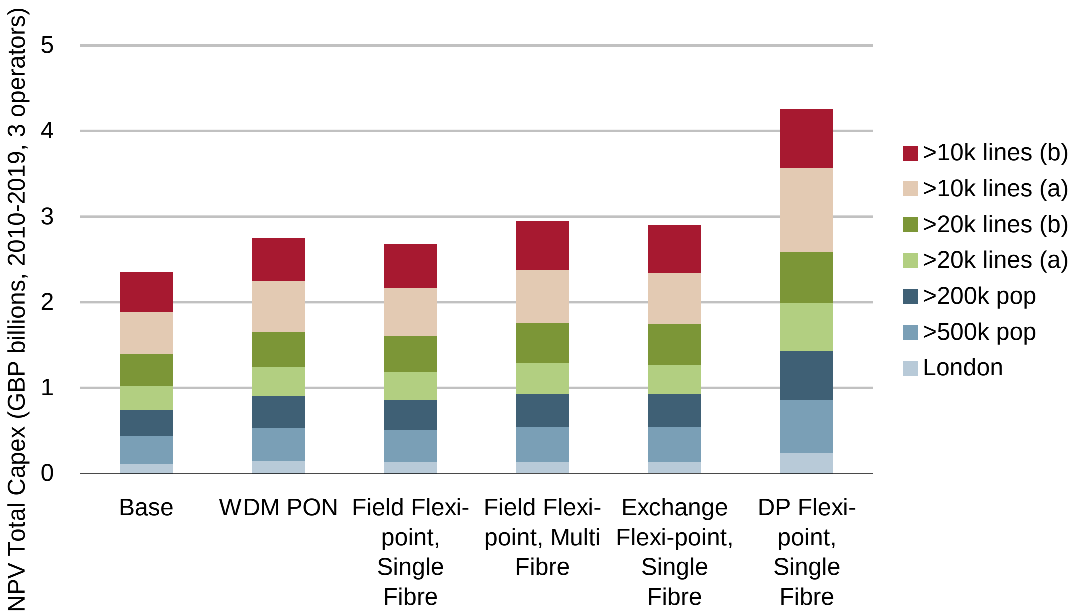


Figure 4.2: Total capex (2010–2019) broken down by geotype under the six scenarios [Source: Analysys Mason]

We have also compared the results produced by the cost model developed for this project with the modelling results produced by Analysys Mason's fibre costing work for the Broadband Stakeholder Group.[17] As can be seen in Figure 4.3, the two studies produced very similar results.

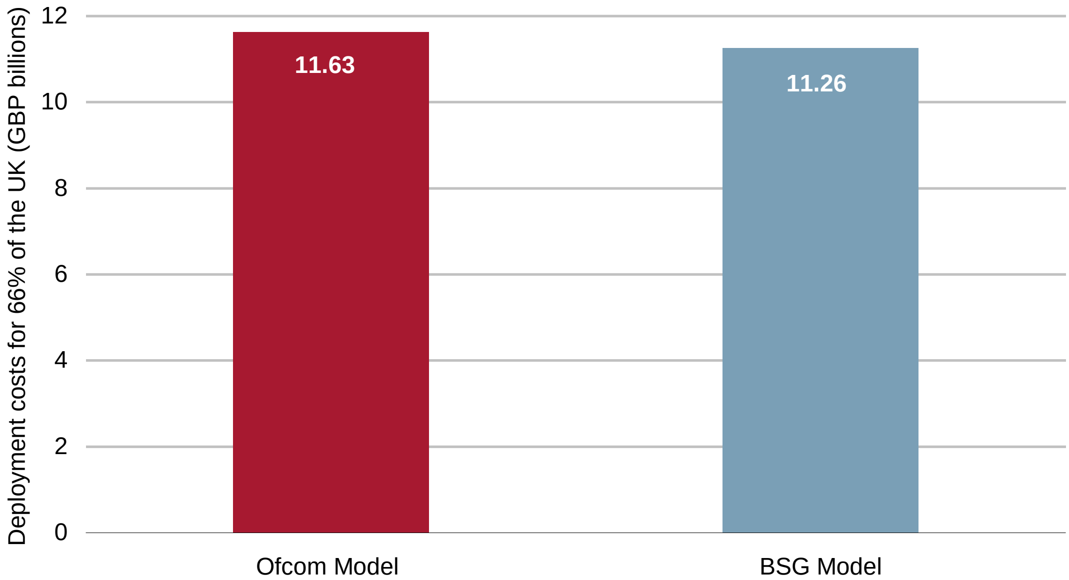


Figure 4.3: Cost to cover 100% of homes in seven geotypes (66% of UK) [Source: Analysys Mason]

[17] See http://www.broadbanduk.org/fibrecosts

Note that in order to provide a valid comparison, we have made some adjustments made to both models. The Ofcom model was adjusted to assume 100% of homes are passed, and the capex costs were discounted at 3.5% (as the BSG model did not consider the time value of money). The BSG costs were adjusted to model deployment of GPON to 66% of UK residential lines (in line with the Ofcom model).

4.3 Costs for incumbent and alternative operators

The cost model calculates separate capex and opex costs for an incumbent and an altnet. These costs are then used to calculate the cost of competition, by adding the incumbent costs to *n* times the altnet costs. Below, we consider the costs for the two types of operator in turn.

4.3.1 Costs for an incumbent

The **capex** for an incumbent with a 33% share of the non-cable NGA broadband retail market is shown in Figure 4.4 below. Again, this covers the period 2010–2019. As can be seen, capex is dominated by the deployment of new duct. For the purpose of modelling the cost of competition, it is assumed that all new duct is deployed by the incumbent (and not by any of the altnets). Civil works and duct costs rise from GBP1.3 billion in the base case to GBP1.6 billion where the flexipoint is located in the exchange. This is due to more fibre being deployed in the latter case, with an assumed reduction in the availability of duct.

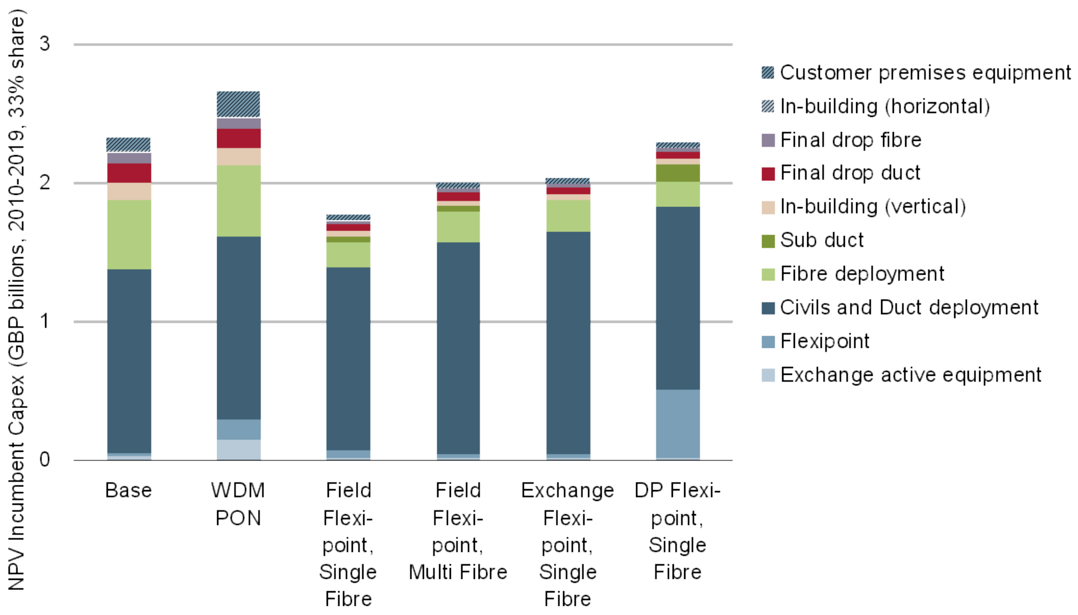


Figure 4.4: Breakdown of capex (2010–2019) for incumbent under the six scenarios [Source: Analysys Mason]

The **opex** for an incumbent with 33% retail market share is shown in Figure 4.5 below. Opex is presented for the year 2015, five years after the start of deployment, to give a figure which is representative of established operations.

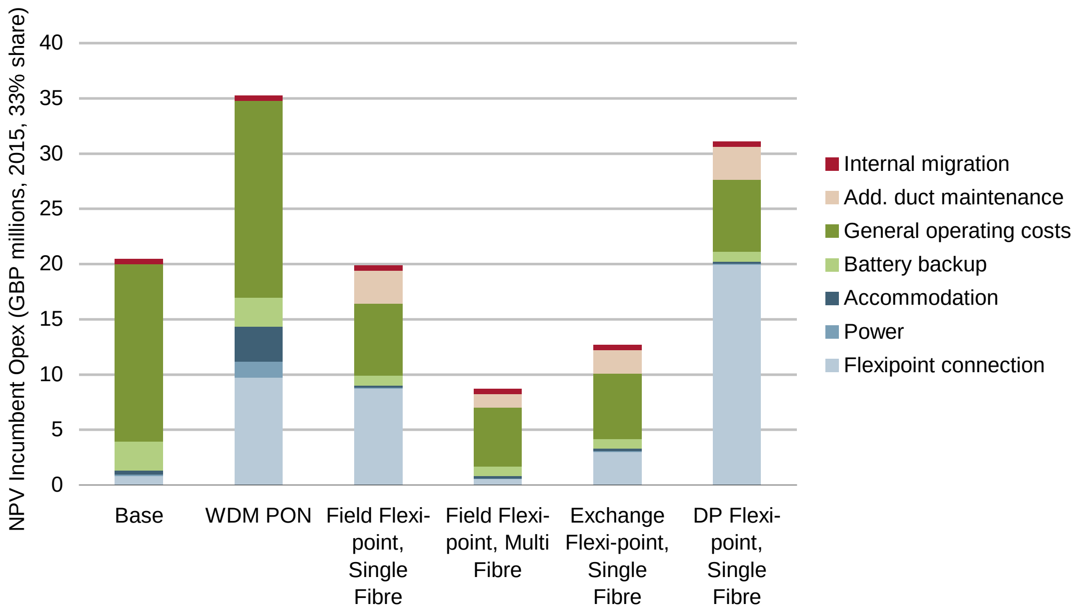


Figure 4.5: Breakdown of opex (2015) for incumbent under the six scenarios [Source: Analysys Mason]

In the Base and WDM PON scenarios, opex is dominated by 'general' operating costs, including provision, maintenance, support and billing. In these two scenarios the incumbent has to meet all of these costs, as it is the only NGA operator. In the other scenarios (involving a flexipoint), the incumbent pays only a share of the general operating costs, but must also pay additional maintenance costs that arise from providing access to its duct. Battery backup replacement is treated in the same way as general operating costs.

4.3.2 Cost for an altnet

The **capex** for an altnet with 33% retail market share, operating from 2010 to 2019, is shown in Figure 4.6 below. To calculate the cost of competition, we have assumed that only the incumbent incurs network deployment capex in the base case and the WDM PON scenario, and therefore altnet network deployment capex is zero for these cases. (Note that both the incumbent and altnet will incur capex to deploy and replace line-termination CPE, and to deploy switch equipment in the exchange). For the flexipoint scenarios, the proportions of costs are the same as for the incumbent, but without the costs of deploying duct.

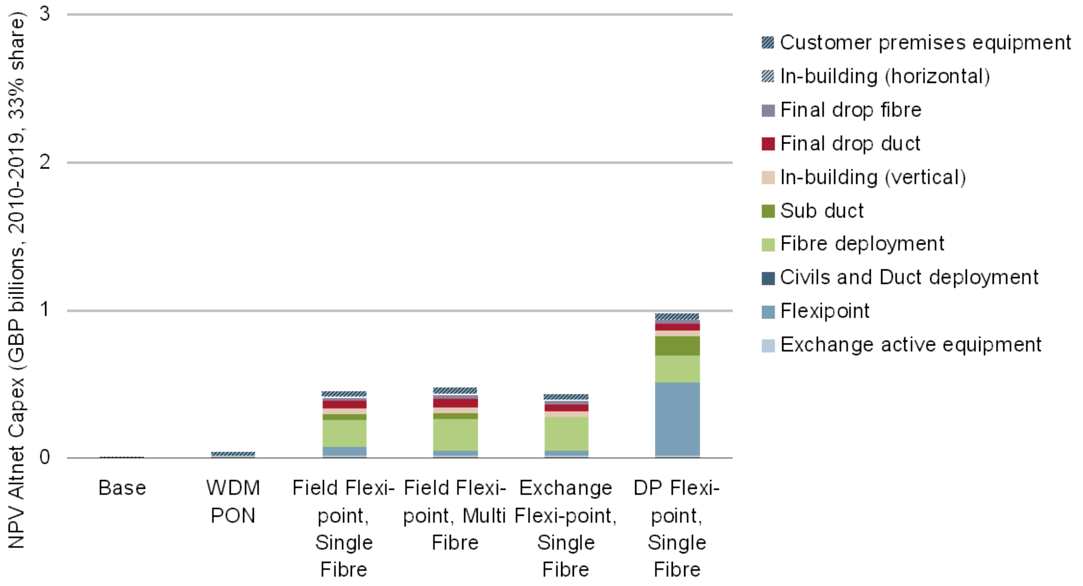


Figure 4.6: Breakdown of capex (2010–2019) for an altnet under the six scenarios [Source: Analysys Mason]

The **opex** for an altnet with 33% retail market share is shown in Figure 4.7 below. We have again presented the opex for the year 2015, five years after the start of deployment.

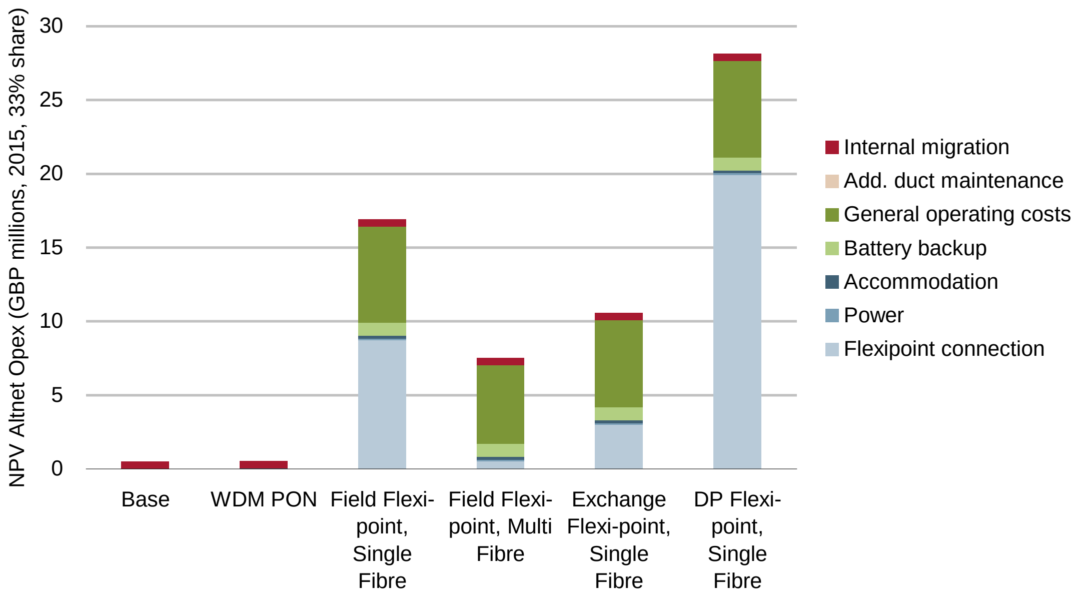


Figure 4.7: Breakdown of opex (2015) for an altnet under the six scenarios [Source: Analysys Mason]

Although an altnet incurs almost no capex in the base case and the WDM PON scenario, we do assume that it would incur an internal migration charge for initial connections and churners. The opex costs for the flexipoint scenarios are the same as for the incumbent (without the additional duct maintenance cost). When the flexipoint is located at the distribution point, flexipoint connection costs become a large proportion (71%) of the opex, due to the large number of locations that need to be visited by engineers when customers connect or churn. For comparison, there are approximately 4.3 million distribution points in the UK compared to around 90 000 cabinets.

4.4 Static cost of competition: results

This section presents a selection of results showing how the static cost of competition is affected by a number of factors such as the number of players in the market, the level of coverage and so on. We have modelled the static cost of competition by assigning depreciation periods to each cost item, and calculating the NPV of the total recovered cost per connected line per month (for 2010–2019). In the following section we will discuss the sensitivity analysis that we carried out on these results.

Number of players

The static cost of competition for each scenario with different numbers of players in the retail market is shown in Figure 4.8 below.

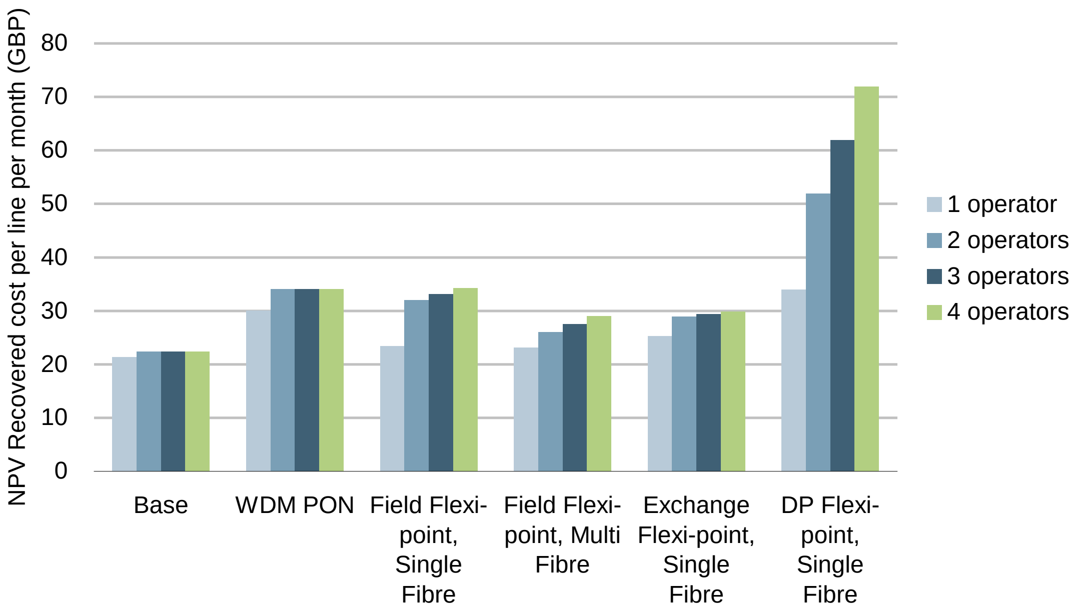


Figure 4.8: *Static cost of competition (2010–2019) under the six scenarios, for a retail market with 1–4 operators [Source: Analysys Mason]*

The recovered cost per line per month ranges from GBP21 in the base case with one operator, to GBP72 in the 'DP Flexipoint, Single Fibre' scenario with four operators. For the base case and the WDM PON scenario, the cost increase to support competing operators is small (arising just from internal migration and line-termination CPE replacement costs). However, the difference in the cost increase between the two scenarios is more significant. For WDM PON technology, which would support greater control over services by operators, the increase in cost per line is around GBP9–12 per line per month (an increase of approximately 41–53%).

For the flexipoint scenarios, there is a greater increase in cost per line as the number of operators in the retail market increases. For the 'Field Flexipoint, Multi Fibre' scenario, it costs GBP3 per line per month to support a second operator (an increase of approximately 13%) than it did with just one, and an extra GBP1 to support each additional operator after the second (approx. 5% increase). Compared to the Base scenario, with three operators in the retail market, the 'Field Flexipoint, Multi Fibre' scenario costs GBP5 extra per line per month (an increase of 23%).

Note: results for one operator in the unbundling scenarios show the cost of deploying the infrastructure for multiple operators (e.g. flexipoint cabinets) but where only one infrastructure operator is active. In reality, a market scenario with only one active infrastructure operator would be equivalent to the Base scenario.

Level of coverage

The effect of the coverage level in each geotype on the monthly recovered cost per line (2010–2019, for a retail market with three players) is shown in Figure 4.9 below. With higher coverage levels, the fixed costs are shared between more end users. For example the cost per line per month in the base case reduces from GBP22.35 at 25% coverage to GBP22.07 per line at 100% coverage.

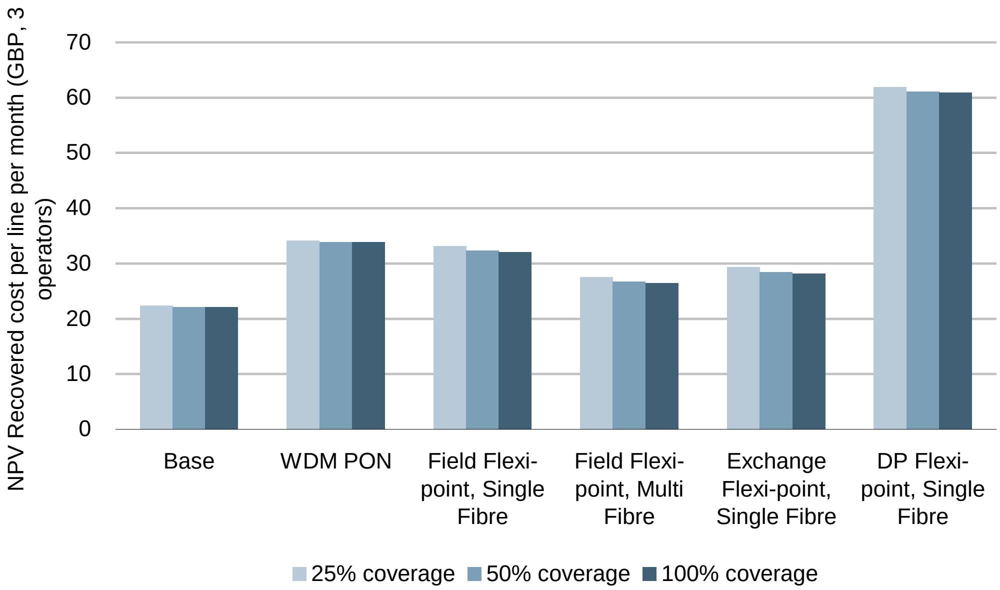


Figure 4.9: *Recovered cost per line per month (2010–2019) under the six scenarios, for different coverage levels [Source: Analysys Mason]*

The various fixed and variable components of capex costs within the recovered cost per line for different coverage levels is shown for the 'Field Flexipoint, Multi Fibre' scenario in Figure 4.10 below. It can be seen that the costs relating to fibre, civil works and duct deployment (of which a component is fixed) vary with coverage level.

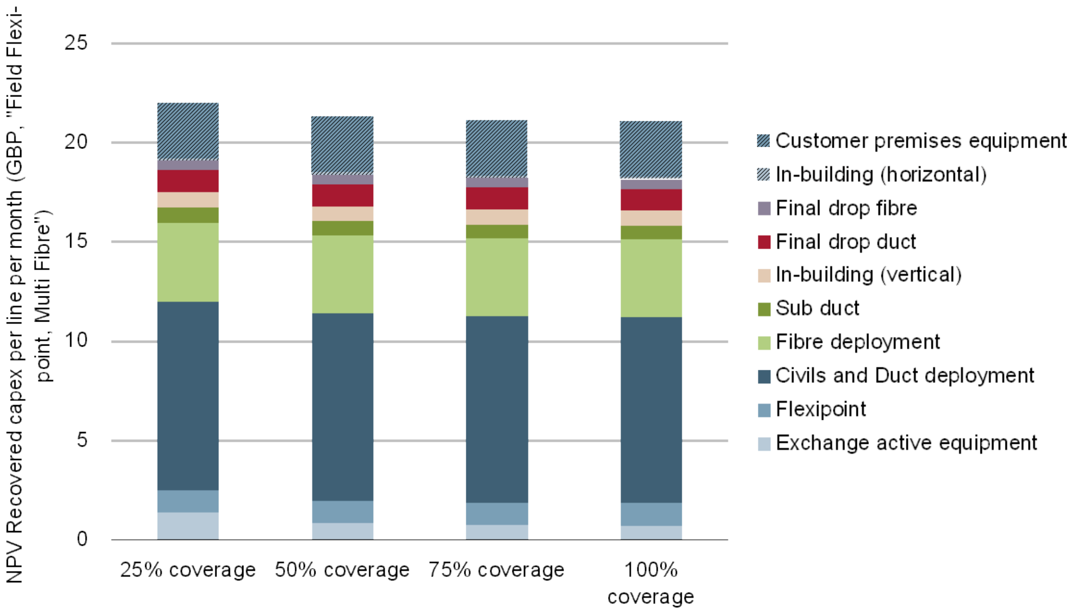


Figure 4.10: *Breakdown of recovered capex per line for the 'Field Flexipoint, Multi Fibre' scenario (2010–2019) for different levels of coverage [Source: Analysys Mason]*

Amount of duct re-use

The effect on the recovered cost per line per month of applying different assumptions for the amount of duct re-use is shown in Figure 4.11 below. The availability of duct has a similar effect in all scenarios, reducing cost per line per month by between GBP3 and GBP4 in the high re-use case, and increasing it by between GBP4 and GBP5 in the low re-use case. Selectively deploying in free duct (to achieve a 95% duct re-use factor) has a large effect on the cost per month, reducing the cost per line in the Base scenario to just GBP15 per month.

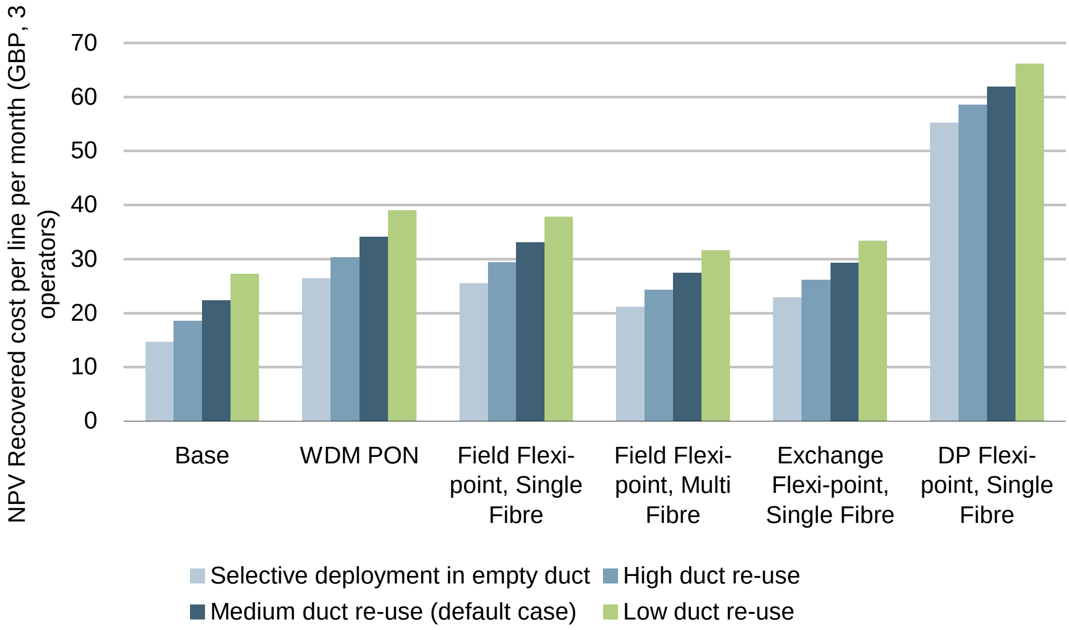


Figure 4.11: Recovered cost per line per month (2010–2019) for different levels of duct re-use [Source: Analysys Mason]

Breakdown of recovered cost per line by number of operators

A breakdown of the recovered **capex** per line per month for the 'Field Flexipoint, Multi Fibre' scenario for different numbers of operators is given in Figure 4.12 below. Note that these results are for the default set of assumptions (25% geotype coverage, medium duct re-use). The effect of deploying parallel fibre is limited, as this is only done in the portion of the network between the cabinet and the exchange. The effect of deploying sub-duct can be clearly seen.

A breakdown of the recovered **opex** per line per month for the same scenario is given in Figure 4.13 below. Although we have assumed that providing duct access effectively doubles the incumbent's per-line maintenance charge, the effect on recovered opex is small, adding just GBP0.27 per month.

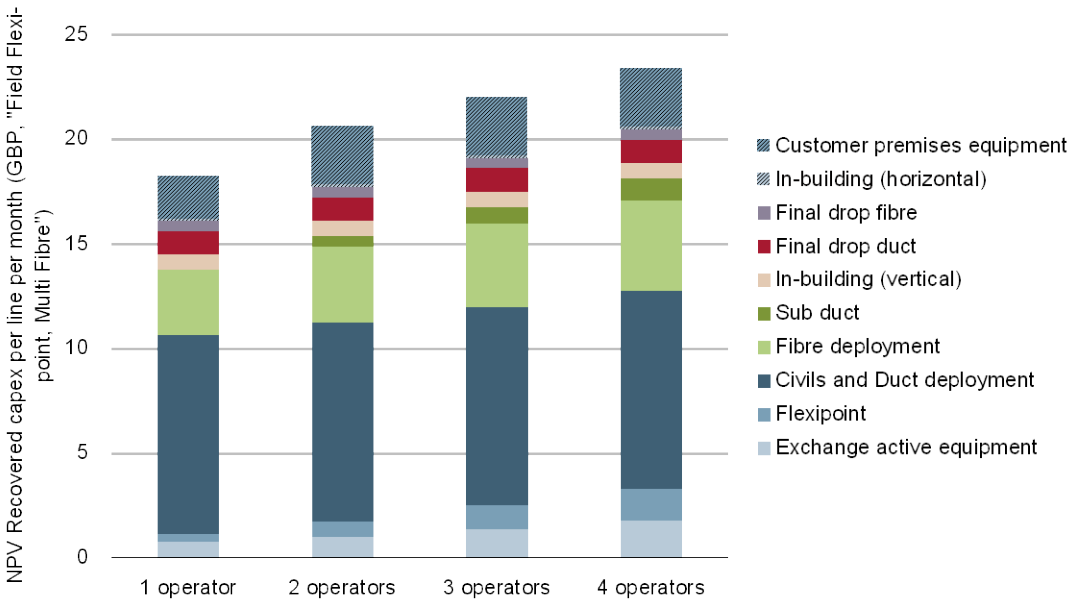


Figure 4.12: Breakdown of recovered capex per line per month (2010–2019) for the 'Field Flexipoint, Multi Fibre' scenario with 1–4 operators [Source: Analysys Mason]

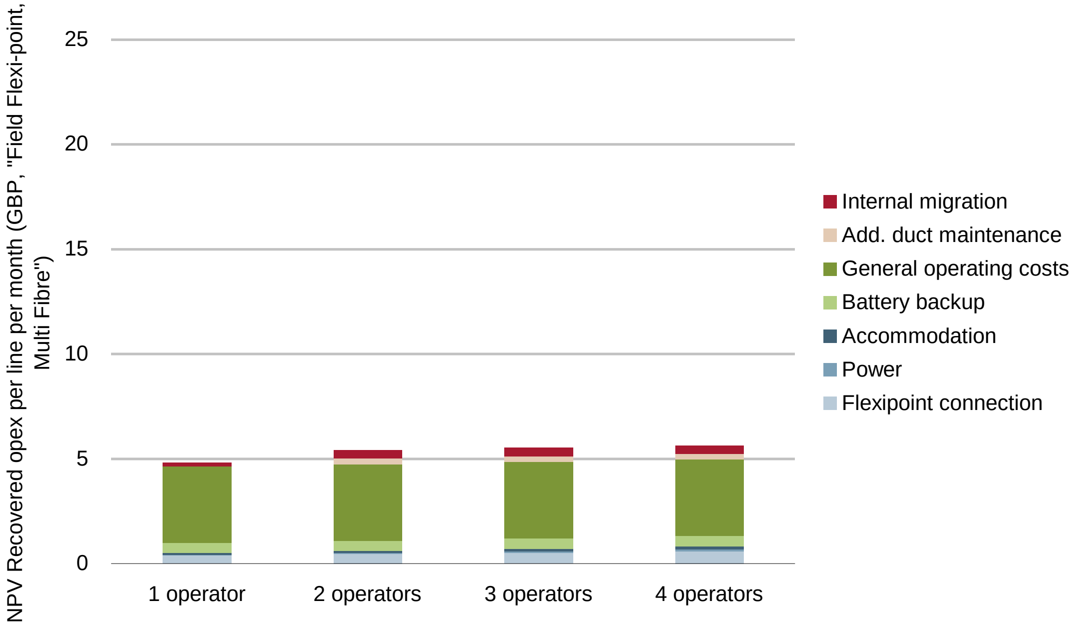


Figure 4.13: Breakdown of recovered opex per line per month (2010-2019) for the 'Field Flexipoint, Multi Fibre' scenario with 1–4 operators [Source: Analysys Mason]

Breakdown of recovered cost per line by scenario

In the figures below, we have given the breakdown of recovered capex and opex per line for each of the six unbundling scenarios (for a retail market with three operators).

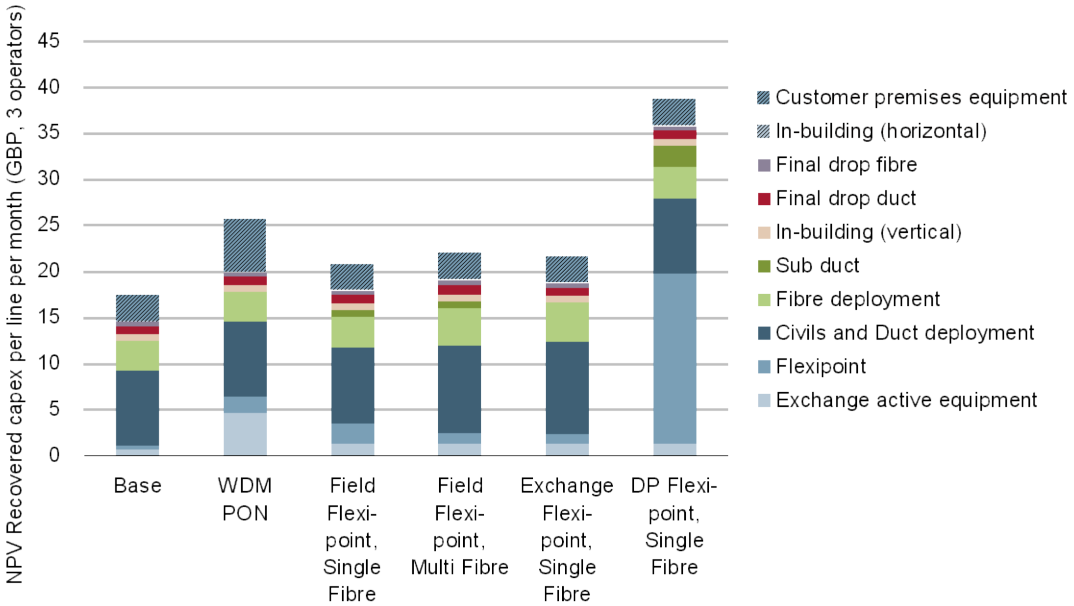


Figure 4.14: *Recovered capex per line per month (2010–2019) for the six scenarios, in retail market with three operators [Source: Analysys Mason]*

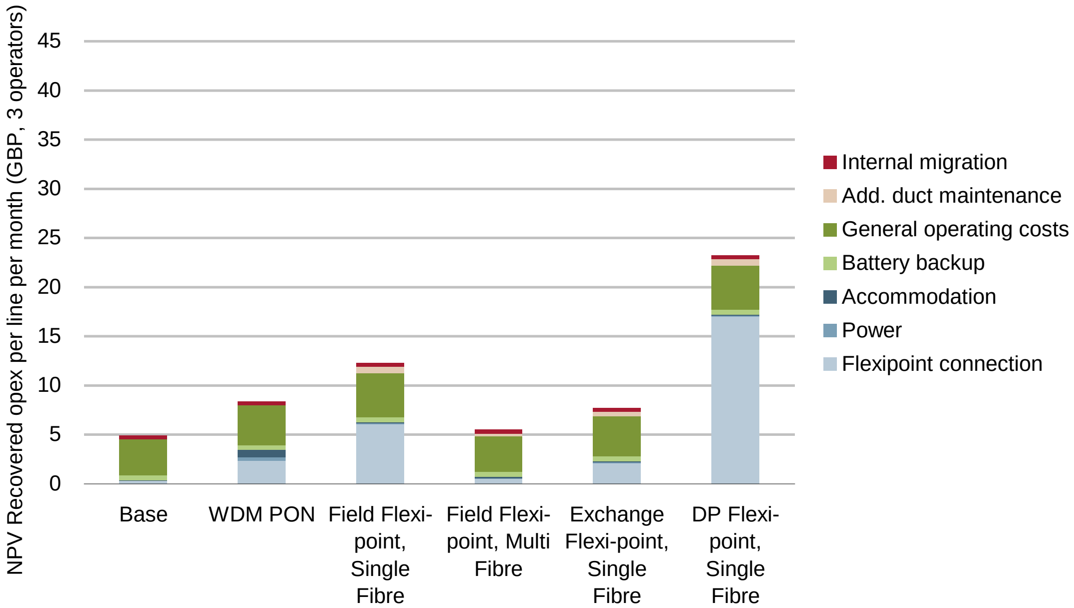


Figure 4.15: *Recovered opex per line per month (2010–2019) for the six scenarios, in retail market with three operators [Source: Analysys Mason]*

Geotype

We have calculated how the cost of competition varies by geotype for the six scenarios (see Figure 4.16). In London the difference between the Base scenario and the 'DP Flexipoint' scenario is GBP30 per line per month. In the most sparsely populated geotype (namely >10k lines (b)), this difference increases to GBP33 per line per month. It should be noted that some low-density geotypes have lower cable coverage, which reduces costs by effectively increasing take-up.

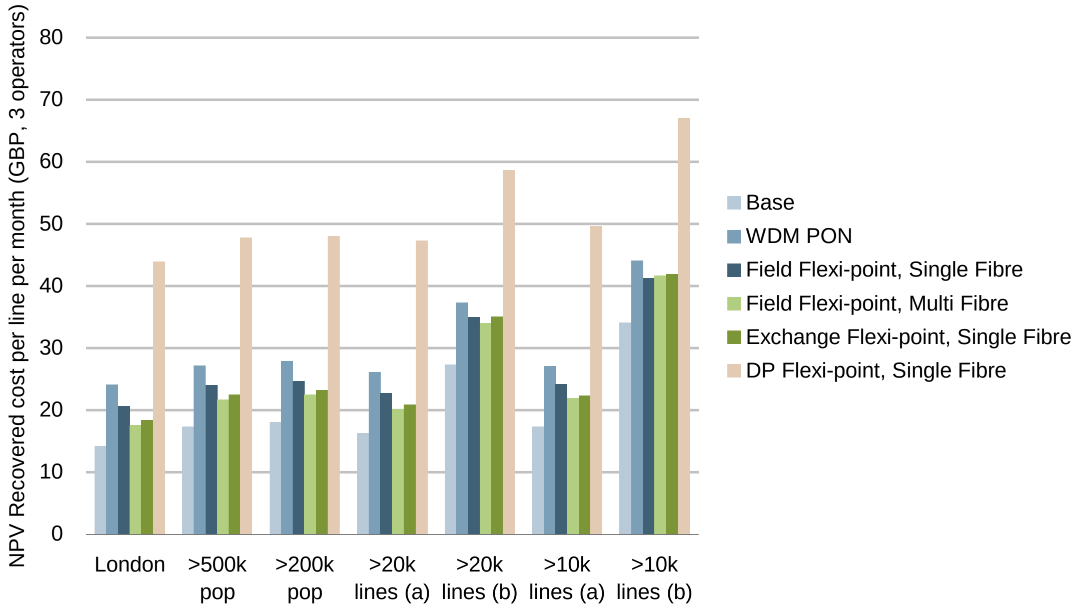


Figure 4.16: Recovered cost per line per month (2010–2019) by geotype [Source: Analysys Mason]

4.5 Static cost of competition: sensitivity analysis

We have tested a number of sensitivities to the cost of competition, as described in Section 3.5 above. The results of this sensitivity analysis are shown in the charts below. All results are for a retail market with three operators, each with 33% market share.

Presence of FTTC

The effect on the recovered cost per line of sharing duct deployment costs with an FTTC roll-out is shown in Figure 4.17 below. As can be seen, the impact is small, creating an average reduction of GBP0.76 per line per month compared with when all duct costs are borne by the FTTP deployment. This is because it is only the duct in the first two sections of the network (exchange to cabinet) that can be shared, and this represents a relatively small proportion of the total.

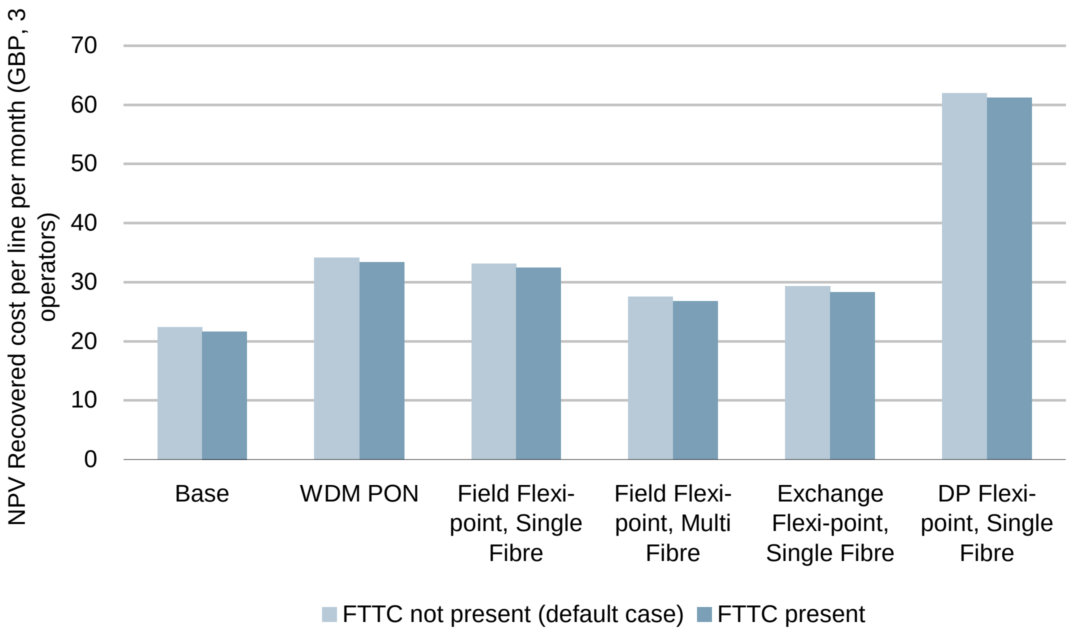


Figure 4.17: Effect of presence of FTTC on recovered cost per line per month (2010–2019) [Source: Analysys Mason]

Split ratio

The effect of doubling the split ratio of the PON networks can be seen in Figure 4.18 below. In the scenarios that use GPON, doubling the split ratio has very little effect because GPON OLT cards are already assumed to support a large number of users (640 per card) and, due to the limited FTTP roll-out, many cards are only partially utilised even in the base case. For WDM PON the effect of doubling the split ratio is more pronounced, creating a GBP3 reduction in the cost per line per month.

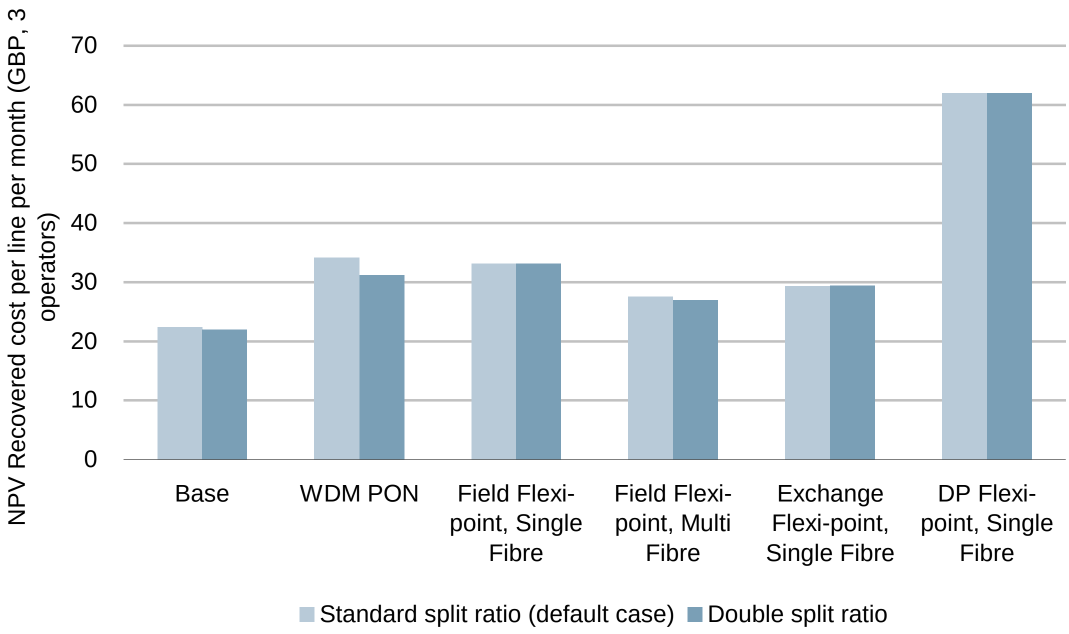


Figure 4.18: *Effect of doubling PON split ratio on recovered cost per line per month (2010–2019) [Source: Analysys Mason]*

NGA take-up

The effect of different levels of NGA take-up is shown in Figure 4.19 below. This has a significant effect on the cost per line per month, as it affects the number of users between which the various fixed costs are shared. If the level of take-up rises to over 90% of broadband subscribers by 2019 (as in the high take-up case), then this creates a reduction of GBP4 per line per month in costs for the Base scenario when compared to the medium take-up case (with 49% take-up by 2019). However, the effect of low take-up is dramatic: if NGA take-up only rises to 19% by 2019, this increases the cost for the Base scenario by GBP11 per line per month.

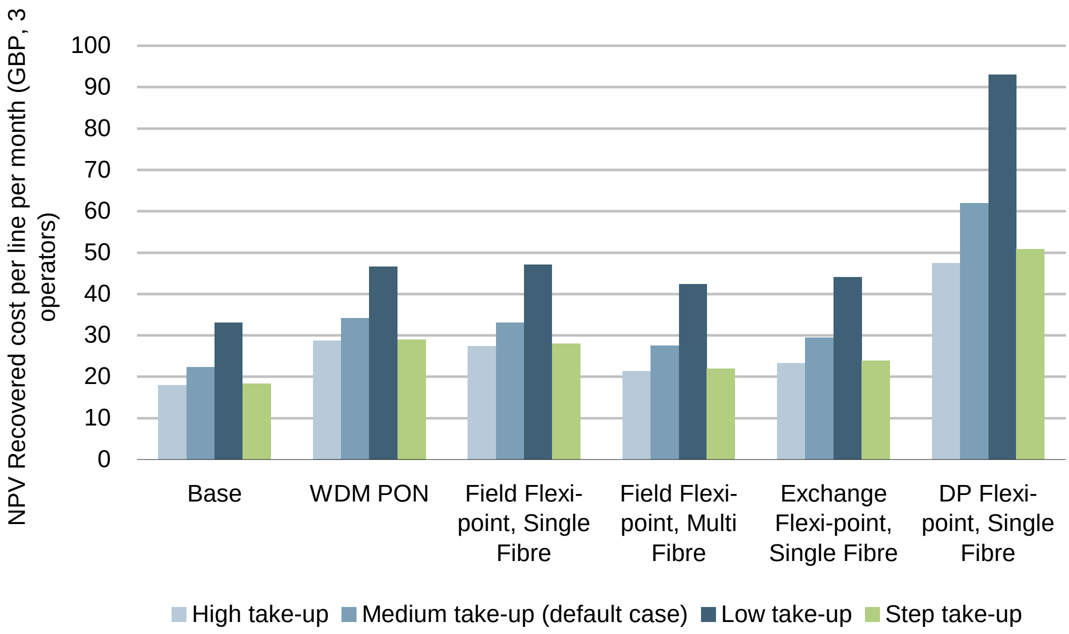


Figure 4.19: Effect of different levels of NGA take-up on recovered cost per line per month (2010-2019) [Source: Analysys Mason]

CPE replacement

In the results so far, we have assumed that line-termination CPE must be replaced when a customer churns. If standards were developed that meant that a user could keep their existing line-termination CPE for a new service provider, this would result in cost savings. The effect of not replacing the CPE when a subscriber churns is shown in Figure 4.20 below. The overall effect on the cost of competition is small. In the GPON scenarios (base and flexipoint), where an altnet provides its own CPE, the additional cost of replacing CPE with churn is GBP0.75 per line per month. This is due to an expected average churn rate of each customer churning every five years, and assumed reductions in the cost of CPE. The effect of CPE replacement is higher in the WDM PON scenario, for which the expected difference in cost is GBP1.88 per line per month.

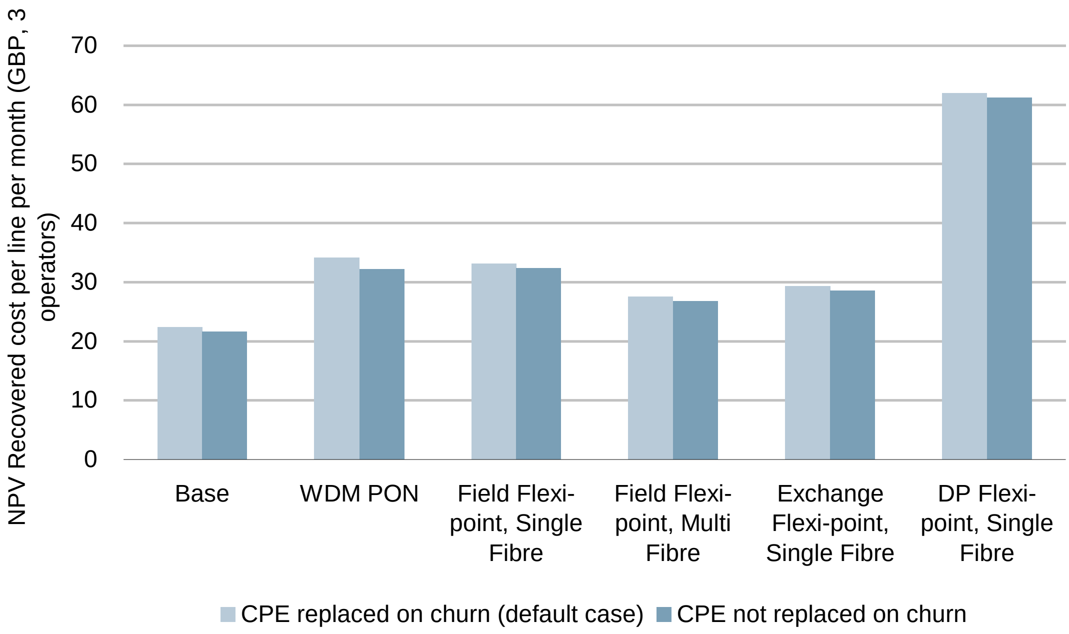


Figure 4.20: Effect of not needing to replace CPE with churn on recovered cost per line per month (2010– 2019) [Source: Analysys Mason]

Timing of WDM deployment

We have assumed that WDM deployment will begin in 2010, and that the prices for WDM PON equipment will fall over the forecast period. However, we have also considered the effect of waiting until the price of WDM PON equipment has bottomed out. To model this, we have set the cost of this equipment for all years in the forecast period (2010–2019) to be the 2019 value in the original assumptions.

The results of this sensitivity are shown in Figure 4.21 below: by waiting for costs to fall before deploying a WDM network, the monthly premium per line over the base case is reduced from GBP12 to GBP7.

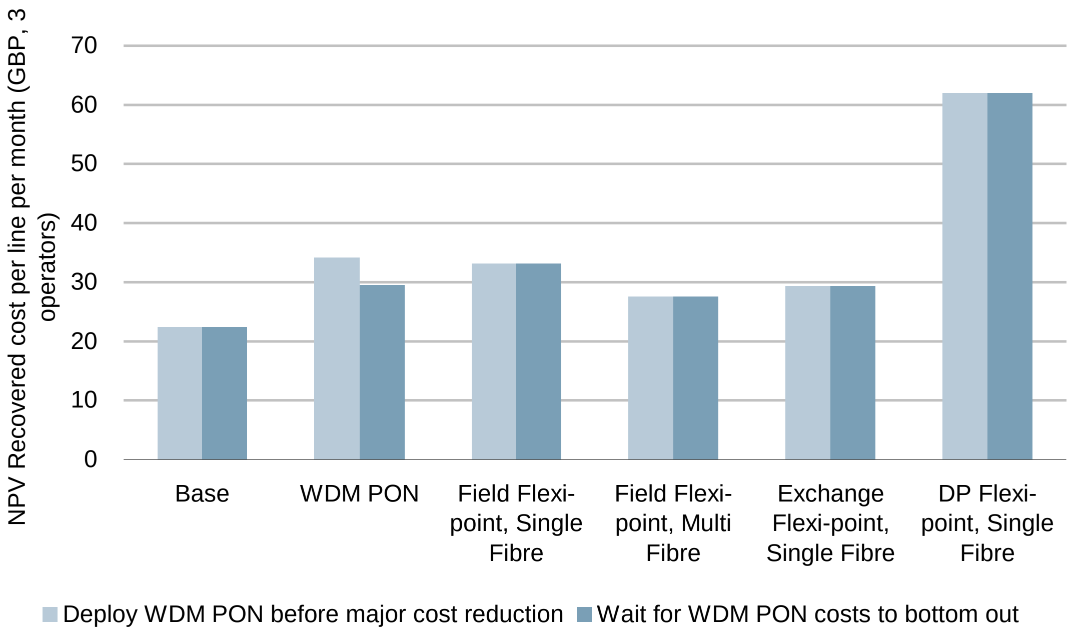


Figure 4.21: Effect of delaying WDM deployment on recovered cost per line per month (2010–2019) [Source: Analysys Mason]

4.6 Cost per home passed and home connected

The cost per home passed and the cost per home connected for various numbers of operators under each of the six unbundling scenario are given in the charts below. We have included the costs for deployment of FTTC/VDSL with one operator as a comparison.[18] We have calculated the cost per home passed by summing the capex (excluding final drop and CPE) and dividing by the number of all the homes in the FTTP coverage area (assumed to be 25% of each geotype). The cost per home connected is the total capex divided by the peak number of homes connected to FTTP services.

18 The cost of deploying FTTC/VDSL for the seven geotypes is derived from our cost modelling work for the BSG.

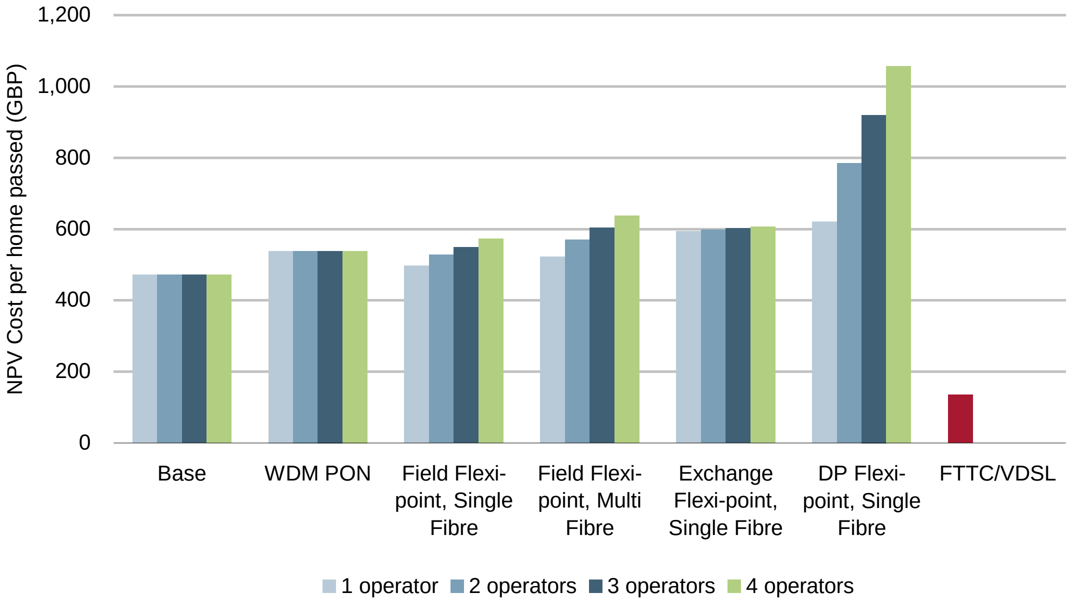


Figure 4.22: Cost per home passed for 1–4 operators [Source: Analysys Mason]

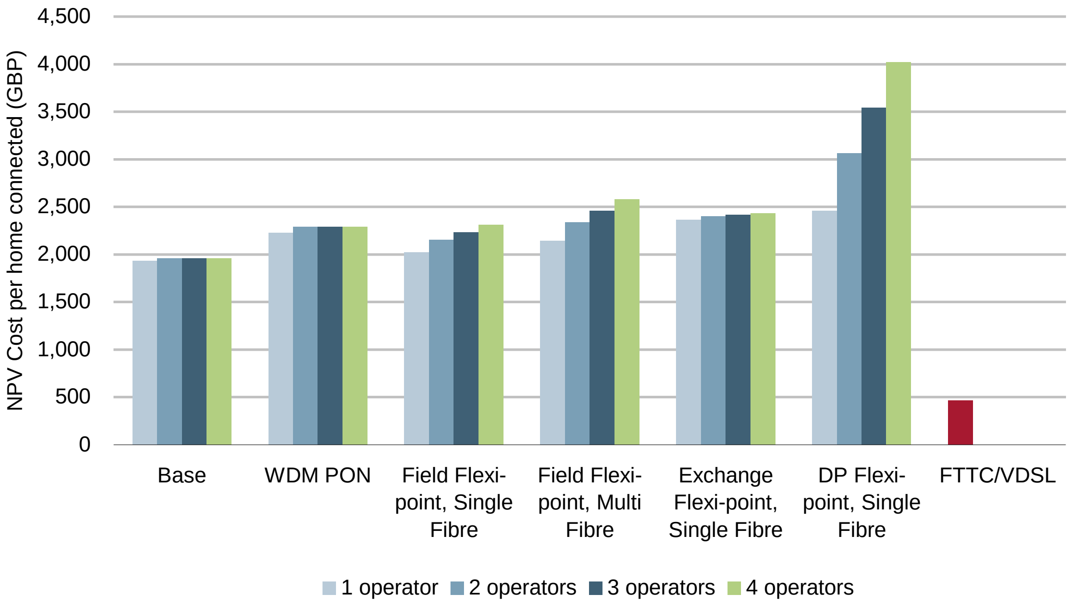


Figure 4.23: Cost per home connected for 1–4 operators [Source: Analysys Mason]

The cost of passing and connecting homes for FTTC/VDSL is significantly less than any of the GPON unbundling scenarios. The ratios of these costs (passed : connected) for the Base scenario is GBP472 : 1933 (approx. 1 : 4.1) and for FTTC/VDSL it is GBP136 : 467 (approx. 1 : 3.4). This cost difference is primarily because FTTC/VDSL uses the existing copper infrastructure between the cabinet and the home, and does not require the installation of additional duct and fibre in this large part of the network.

4.7 Breakeven for national deployment by an incumbent

We have considered whether an incumbent can break even on a national basis under a range of different conditions. **It should be noted that the scenarios have been modelled on a standalone basis.** We have not considered the implications of mixed deployments of active and passive unbundling options. The viability of the business cases described below may be affected if there are competing models of unbundling in the market.

We have conducted a breakeven test (by calculating the NPV plus terminal value) at five and ten years after deployment. The test was carried out for each unbundling scenario and for a range of market shares. In the first set of results, presented below, the input assumptions are the same as for the cost-of-competition calculations, e.g. FTTP coverage of 25% in exchange areas covering approximately 66% of homes. Note that the revenue received in the base case and WDM PON scenario is wholesale-only, and we have assumed that this is GBP25 per line per month initially, falling to GBP20 at the end of the forecast period (compared to GBP45 per line retail). We have assumed that the incumbent would be responsible for deploying all additional duct required by the whole market.

Note that in the following tables, results for the Base and WDM PON scenarios are only shown for a market share of 100%, as in these scenarios the incumbent is assumed to have 100% of the wholesale NGA market.

Market share	*Base case**	*WDM PON**	*Field Flexipoint, Single Fibre*	*Field Flexipoint, Multi Fibre*	*Exchange Flexipoint, Single Fibre*	*DP Flexipoint, Single Fibre*
25%	N/A	N/A	-1,244	-1,408	-1,440	-1,986
33%	N/A	N/A	-1,187	-1,321	-1,380	-1,940
50%	N/A	N/A	-1,067	-1,134	-1,254	-1,842
66%	N/A	N/A	-955	-958	-1,136	-1,752
75%	N/A	N/A	-893	-859	-1,070	-1,701
100%	-1,389	-1,928	-348	-473	-740	-1,102

* In these scenarios the incumbent is assumed to have 100% of the wholesale NGA market.

Figure 4.24: NPV+TV at 5 years for an incumbent (GBP millions) [Source: Analysys Mason]

Market share	*Base case*	*WDM PON*	*Field Flexipoint, Single Fibre*	*Field Flexipoint, Multi Fibre*	*Exchange Flexipoint, Single Fibre*	*DP Flexipoint, Single Fibre*
25%	N/A	N/A	-1,098	-1,217	-1,262	-1,857
33%	N/A	N/A	-995	-1,069	-1,144	-1,764
50%	N/A	N/A	-777	-752	-897	-1,568
66%	N/A	N/A	-575	-456	-668	-1,387
75%	N/A	N/A	-462	-290	-539	-1,286
100%	-1,261	-1,883	418	297	40	-353

Figure 4.25: NPV+TV at 10 years for an incumbent (GBP millions) [Source: Analysys Mason]

We have also considered the impact of wholesale revenue being more closely ‘pegged’ to current levels initially, but then rising to deliver a premium over time. The table below shows the results with the Base and WDM PON scenarios delivering GBP15 per line per month revenue initially, which then rises to GBP20 at the end of the forecast period.

Market share	*Base case*	*WDM PON*	*Field Flexipoint, Single Fibre*	*Field Flexipoint, Multi Fibre*	*Exchange Flexipoint, Single Fibre*	*DP Flexipoint, Single Fibre*
25%	N/A	N/A	-1,098	-1,217	-1,262	-1,857
33%	N/A	N/A	-995	-1,069	-1,144	-1,764
50%	N/A	N/A	-777	-752	-897	-1,568
66%	N/A	N/A	-575	-456	-668	-1,387
75%	N/A	N/A	-462	-290	-539	-1,286
100%	-1,403	-2,026	418	297	40	-353

Figure 4.26: NPV+TV at 10 years for an incumbent, with wholesale revenue initially pegged to current values then rising. (GBP millions) [Source: Analysys Mason]

We have also considered the effect of a favourable set of deployment conditions. The tables below show the combined effect of (a) maximising duct re-use with innovative ducting techniques (using the ‘high’ duct re-use assumptions), (b) avoiding the sparsely populated ‘b’ geotypes (and so covering 53% of homes), (c) extending deployment to 100% of homes, and (d) maintaining both wholesale and retail average prices at a constant level (GBP25 and GBP45 per line per month respectively). It should be noted that if the deployment is extended to include the sparsely populated geotypes, then the business case could become more challenging.

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Market Share	*Base case*	*WDM PON*	*Field Flexipoint, Single Fibre*	*Field Flexipoint, Multi Fibre*	*Exchange Flexipoint, Single Fibre*	*DP Flexipoint, Single Fibre*
25%	N/A	N/A	-1,342	-1,911	-1,978	-3,723
33%	N/A	N/A	-1,117	-1,589	-1,727	-3,536
50%	N/A	N/A	-638	-902	-1,193	-3,141
66%	N/A	N/A	-188	-244	-690	-2,768
75%	N/A	N/A	63	121	-409	-2,560
100%	-1,009	-2,746	1,906	1,440	840	-576

Figure 4.27: NPV+TV at five 5 years for an incumbent under favourable deployment conditions (GBP millions) [Source: Analysys Mason]

Market Share	*Base case*	*WDM PON*	*Field Flexipoint, Single Fibre*	*Field Flexipoint, Multi Fibre*	*Exchange Flexipoint, Single Fibre*	*DP Flexipoint, Single Fibre*
25%	N/A	N/A	-862	-1,284	-1,391	-3,295
33%	N/A	N/A	-484	-763	-953	-2,956
50%	N/A	N/A	317	348	-24	-2,237
66%	N/A	N/A	1,072	1,404	851	-1,560
75%	N/A	N/A	1,496	1,995	1,344	-1,179
100%	90	-1,887	4,443	3,989	3,419	1,909

Figure 4.28: NPV+TV at 10 years for an incumbent under favourable deployment conditions (GBP millions) [Source: Analysys Mason]

The effect of each component of the above set of conditions is shown in Figure 4.29 below for the 'Field Flexipoint, Multi Fibre' scenario at 50% market share. It can be seen that increasing the amount of duct re-use and targeting denser geotypes has a significant effect on the breakeven test – these elements add GBP828 million to the 10-year business case. It can also be seen that once a positive business case has been achieved, increasing the scale of the deployment delivers an even more favourable result – increasing coverage from 25% to 100% adds another GBP272 million to the 10-year business case.

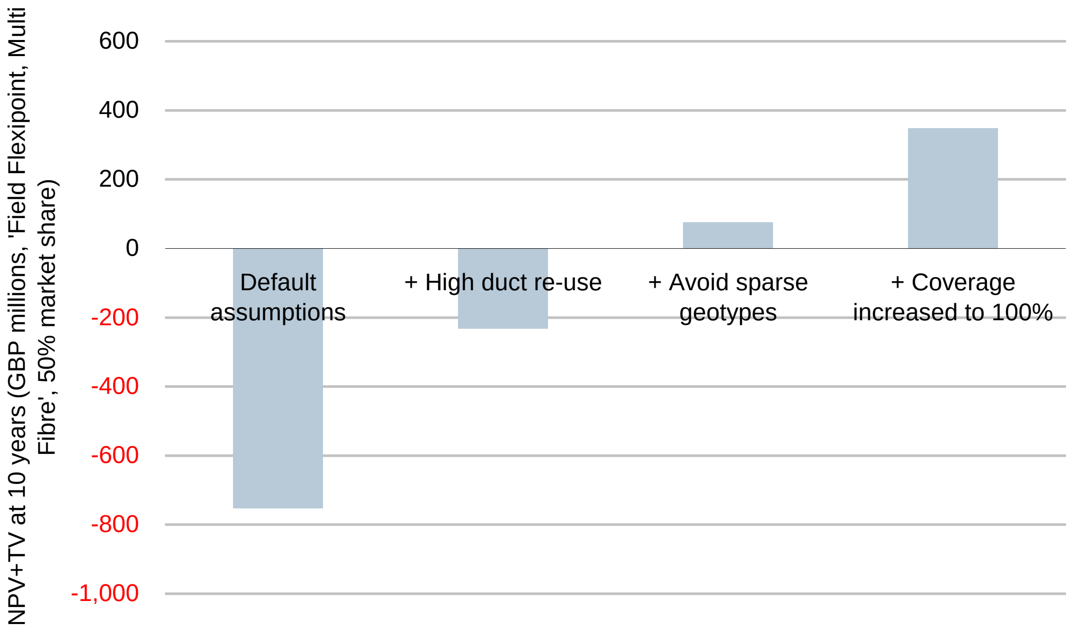

Figure 4.29: Effect of each component of the favourable deployment conditions on incumbent's NPV+TV at 10 years (GBP millions) [Source: Analysys Mason]

Finally, we have considered the effect of the incumbent receiving revenue from the duct it rents out to alternative operators (see tables below). Note that all the assumptions modified in the previous sensitivity test have been returned to default levels (i.e. 25% coverage, medium duct re-use, and revenue falling due to competition) in order to isolate the effect of receiving duct income. The income received from duct is higher when the incumbent has lower market share, as the modelling assumes that the total number of players in the market is the reciprocal of the current market share (i.e. 25% market share = four players in the market = three altnets providing revenue).

Market Share	*Base case*	*WDM PON*	*Field Flexipoint, Single Fibre*	*Field Flexipoint, Multi Fibre*	*Exchange Flexipoint, Single Fibre*	*DP Flexipoint, Single Fibre*
25%	353	611	2,280	4,127	3,039	2,672
33%	-444	-398	1,089	2,013	1,328	1,208
50%	-1,178	-1,395	-60	34	-259	-297
66%	-1,417	-1,793	-492	-451	-788	-958
75%	-1,467	-1,917	-613	-559	-904	-1,188
100%	-1,389	-1,928	-348	-473	-740	-1,102

Figure 4.30: NPV+TV at five 5 years for an incumbent with duct rental revenue (GBP millions) [Source: Analysys Mason]

Market Share	*Base case*	*WDM PON*	*Field Flexipoint, Single Fibre*	*Field Flexipoint, Multi Fibre*	*Exchange Flexipoint, Single Fibre*	*DP Flexipoint, Single Fibre*
25%	629	909	2,836	4,964	3,740	3,344
33%	-255	-210	1,546	2,654	1,880	1,751
50%	-1,062	-1,309	347	553	214	158
66%	-1,319	-1,740	-57	109	-278	-501
75%	-1,370	-1,870	-150	44	-354	-713
100%	-1,261	-1,883	418	297	40	-353

Figure 4.31: NPV+TV at 10 years for an incumbent with duct rental revenue (GBP millions) [Source: Analysys Mason]

4.8 Share of lines for breakeven by an altnet

We have also considered the extent to which an alternative network operator is likely to deploy any of the unbundling options (again with each of the options modelled on a standalone basis). We have applied the breakeven test (NPV+TV) at ten years in each of the seven geotypes for a variety of retail market shares. Results are provided in the tables below for each unbundling option (we assume that an altnet would not deploy either the Base or WDM PON scenarios). Note that these results assume that any additional duct has already been deployed by the incumbent, and the altnet incurs a cost for renting access to this duct.

The figures shown assume that the altnet would cover 100% of homes in each geotype, and raise its ARPU with inflation.

Market Share	*London*	*>500k pop*	*>200k pop*	*>20k lines (a)*	*>20k lines (b)*	*>10k lines (a)*	*>10k lines (b)*
10%	-106	-374	-330	-266	-738	-363	-576
25%	-50	-284	-259	-174	-754	-237	-651
33%	-21	-239	-223	-127	-764	-174	-693
50%	40	-143	-147	-28	-786	-42	-782
66%	98	-53	-76	66	-807	83	-866
75%	130	-2	-36	118	-819	153	-913
100%	460	737	608	778	-195	1,128	-525

Figure 4.32: NPV+TV at 10 years for an altnet, 'Field Flexipoint, Single Fibre' scenario (GBP millions) [Source: Analysys Mason]

Market Share	*London*	*>500k pop*	*>200k pop*	*>20k lines (a)*	*>20k lines (b)*	*>10k lines (a)*	*>10k lines (b)*
10%	-124	-470	-428	-344	-870	-511	-757
25%	-50	-347	-328	-221	-882	-353	-855
33%	-14	-266	-260	-170	-908	-292	-929
50%	77	-132	-153	-13	-759	109	-797
66%	171	149	102	172	-820	216	-955
75%	224	152	93	272	-789	366	-952
100%	508	874	736	899	-69	1,341	-367

Figure 4.33: NPV+TV at 10 years for an altnet, 'Field Flexipoint, Multi Fibre' scenario (GBP millions) [Source: Analysys Mason]

Market Share	*London*	*>500k pop*	*>200k pop*	*>20k lines (a)*	*>20k lines (b)*	*>10k lines (a)*	*>10k lines (b)*
10%	16	-14	-15	13	-165	23	-146
25%	42	-31	-34	33	-411	65	-363
33%	55	-41	-45	44	-543	87	-479
50%	84	-61	-67	67	-823	134	-726
66%	111	-80	-88	89	-1,086	177	-958
75%	126	-91	-100	102	-1,234	202	-1,088
100%	235	25	-1	274	-1,553	494	-1,364

Figure 4.34: NPV+TV at 10 years for an altnet, 'Exchange Flexipoint, Single Fibre' scenario (GBP millions) [Source: Analysys Mason]

Market Share	*London*	*>500k pop*	*>200k pop*	*>20k lines (a)*	*>20k lines (b)*	*>10k lines (a)*	*>10k lines (b)*
10%	-426	-1,275	-1,180	-1,116	-1,586	-1,941	-1,706
25%	-365	-1,149	-1,069	-996	-1,542	-1,753	-1,691
33%	-333	-1,081	-1,010	-931	-1,519	-1,653	-1,683
50%	-264	-938	-885	-794	-1,470	-1,441	-1,667
66%	-198	-803	-767	-665	-1,423	-1,242	-1,651
75%	-162	-727	-700	-593	-1,397	-1,130	-1,642
100%	270	414	345	426	-258	576	-496

Figure 4.35: NPV+TV at 10 years for an altnet, 'DP Flexipoint, Single Fibre' scenario (GBP millions) [Source: Analysys Mason]

5 Prospects for GPON competition and implications for regulatory policy

In this section we discuss the implications of the cost modelling work, both for the prospects of competition on GPON networks and for what Ofcom may consider doing next. We discuss the implications under four headings: competition based on active equipment, competition based on passive infrastructure, the practicalities of PON deployments, and other policy considerations. At the end of each section, we summarise the implications for Ofcom under the following headings:

- prospects for competition
- BT's potential advantage
- steps to avoid foreclosure
- specific policy implications.

It should be noted that the results produced in this study are indicative, and are designed only to show the differences between various forms of unbundling. In particular, the methodology and results of this study are not intended to inform the setting of prices for either retail or wholesale products.

5.1 Unbundling based on active equipment (Base and WDM scenarios)

5.1.1 Practicalities and scope for innovation

In the study, we have considered two forms of unbundling that are based on an interface with active electronics. In the Base scenario, the operators' interface with the network is based on a layer-2 protocol, which is likely to be Ethernet (as in the proposed active line access (ALA) standard, or BT's GEA). Operators will only need to install Ethernet switch gear at the exchange to interface with the incumbent's OLT cards and deliver services to end users. The second active-equipment-based scenario involves the use of WDM to separate users on the PON. In this case the operator would connect to a particular transponder on the WDM OLT card. Although this method of separating users is well established in the metro and long-haul markets, there are a number of options for assigning the wavelengths to each user, and some standardisation may still be required. In both cases, each operator would have to purchase power and space in the exchange to host its interconnecting equipment, and arrange for backhaul from the exchange to its point of presence.

The Base scenario offers some scope for innovation and differentiation from competitors, but is more restrictive when compared to the other unbundling options considered in this study. Assuming the requirements set out by ALA[19] are met, operators using a layer-2 active interface

19 See http://www.ofcom.org.uk/telecoms/discussnga/eala/updated/

would be able to choose the priorities with which their services are delivered, and also be able to deliver new types of content such as HDTV. However, operators will be constrained by the functionality of the layer-2 protocol offered by the incumbent: this could restrict the way in which service priority is managed, and the choice of bit rates that can be offered to customers.

Compared to the Base scenario, WDM PON offers a significant improvement in the scope for innovation, as WDM transponders are independent of protocol and bit rate. This means that operators can choose their own layer-2 protocols, thus having complete control over the management of their traffic, and they can also choose the selection of download capacities offered to end users (up to the maximum capacity of the PON).

In both active-equipment cases, the purchasing operators (e.g. altnets) will have less freedom to differentiate on price than with competition based on passive infrastructure, as the wholesale charge for active-equipment access will be higher than in the passive access cases.

5.1.2 Feasibility of deployment

In the study, we considered the feasibility of an incumbent deploying networks that would support the two types of active access described above. The results of the breakeven analysis (Section 4.7) showed that with 100% of the wholesale market, 100% population coverage (within the five densest geotypes), high duct reuse and flat pricing, an incumbent should be able to create a viable business case over a 10-year timeframe (although not with a five-year timeframe) for the Base scenario. However, due the higher cost base of WDM PON, it is unlikely that the incumbent will be able to create a viable case over the same timeframe. The viability of both business cases may be improved by a number of factors, including:

- extending the business case to an even longer timeframe (e.g. 15 years and beyond)
- using ready-deployed fibre, e.g. access fibre installed for the business market.
- in the case of WDM PON, waiting until equipment prices have fallen before deploying the network.

A combination or all of these factors may be central to the business case of operators who are rolling out FTTH, or are planning to (including BT).

5.1.3 The cost and prospects for competition

The cost of competition is the additional cost to the consumer arising from there being more than one operator in the retail market. In the Base scenario the cost of competition is small: there is a difference of just GBP1 (5%) in recovered cost per line per month between a retail market with a single operator and one with two operators. This additional cost is due to the duplication of switch equipment, the internal migration costs incurred by each operator when a customer leaves and joins, and the cost of providing a new customer with line-termination CPE. We consider these cost components below.

In terms of reducing the cost of competition to the consumer, it is unlikely that the exchange switch and internal migration components of the cost can be reduced. Switch costs make up only a small proportion of the recovered cost per month, and the cost assumptions are based on mature technology, so it is unlikely that these can be reduced significantly in the future. Internal migration costs were modelled based on Openreach's existing migration costs for IPStream and Datastream, which reduced significantly in 2004,[20] so again it is unlikely that this cost will diminish significantly in the future. Both these costs are unavoidable in the operation of fixed telecoms networks.

The majority of the cost of competition in the Base scenario arises from replacing line-termination CPE[21] each time a customer churns (without competition, it is assumed there would be no churn and the CPE would not be replaced). However, it is possible that this cost of competition may not be incurred: operators may wish to have control of the line-termination CPE to incorporate all the CPE functionality into a single box, in which case this element would effectively be replaced each time a new customer is acquired. However, this approach relies on the infrastructure provider (the incumbent operator in the cases we have modelled) relinquishing control over the equipment that is attached to the customer end of its fibre (as well as certain standards being developed). In the case where the incumbent owns and controls the fibre termination equipment in the home (which may be its preferred *modus operandi*), then the CPE element of the cost of competition would be removed. Consequently, it must be considered whether the innovation benefits of allowing operators to have complete control over all equipment in the customer premises are worth the additional cost (and concerns of the incumbent) of replacing the line terminator with each churning customer.

In the WDM PON scenario, the difference in recovered cost per line per month between a retail market with a single operator and one with two operators is GBP4 (13%). This cost includes the internal migration costs and CPE replacement costs, as in the Base scenario (although the CPE replacement costs are much higher due to the higher cost of WDM equipment). However, around 50% of this cost of competition is associated with the management of churn.

To manage churn on a WDM PON, while still giving access to the layer-1 wavelengths (and the associated potential for operators to innovate), requires the use of an Optical Distribution Frame at the exchange to connect operators to the right transponder. Each time a customer churns, an engineer must visit the exchange to swap over the relevant connectors. This function has an associated capex (for the ODF) and opex (for the engineer to make connections). Automated ODFs could possibly reduce the cost of competition, by removing the opex component in the exchange for a potentially moderate increase in capex. However, it is unclear whether automatic ODFs of the required size to enable many-to-many patching in the exchange will be a practical reality in the near future. Automatic copper MDFs are rare, and tend to be small-scale and expensive; they have

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20 http://www.samknows.com/broadband/news/bt-wholesale-slash-adsl-migration-charges-140.html

21 In the model, we have included the cost of a basic line-termination CPE which does not support additional functions such as home network routeing or a set-top box.

yet to be used in large-scale deployments. It is also unclear whether even manual ODFs of the required size are feasible in terms of size, cost and practical feasibility.

The alternative would to be manage churn on the WDM PON electronically, which would require all the operators to connect via an Ethernet switch. This approach would offer substantial cost savings as there would be no requirement for the ODF or engineer visit. However, using a switch would remove the innovation potential discussed above, as operators would have to adhere to the Ethernet protocols defined by the provider of the switch. The use of a switch would also introduce a degree of contention into the capacity offered to each user. In this case, the WDM PON scenario becomes a version of the Base scenario, albeit with the infrastructure provider having more capacity and flexibility to wholesale. It should be noted that there are indications that the industry may be already heading towards implementing Ethernet as a layer-2 protocol for WDM PON: for example, Nortel's WDM solution is based on Ethernet.[22] However, it will be for the FSAN standardisation body to decide if Ethernet should be the standard protocol for WDM PON.

The management of churn on WDM PON represents a trade-off. To realise the full scope for innovation over the Base scenario requires increases in both capex and opex, which will raise wholesale prices. This increase in costs can be limited, but this results in a reduction in the scope for innovation. The use of automatic ODFs could provide a pragmatic solution, but this is likely to require significant product development to become commercially viable.

Due to the low barriers to entry for altnets, we believe that in a retail market based on active access to an established fibre network there would be good prospects for competition. The costs of entry are relatively low, as LLU operators are likely to be able to leverage their existing exchange presence and backhaul in order to interconnect with the new network. However, this assumption relies on the incumbent (or other infrastructure provider) being able to make a viable business case from the provision of wholesale network access.

It should be noted that an altnet's decision to serve customers via an active interface will be affected by the relative costs and benefits of using the incumbent's infrastructure compared to deploying its own infrastructure (especially in the Base scenario). If the scope for innovation via an active interface constrains an operator's ability to differentiate itself significantly, then deploying parallel infrastructure may become necessary for the operator to compete. In any case, deployment of parallel NGA infrastructure will not be viable everywhere, and therefore 'fit-for-purpose' active access will be essential in an NGA world. It should be noted that the results of our modelling are standalone, and have not considered the effects of both active and passive unbundling scenarios being present in the same market.

22 See http://www.lg-nortel.com/index.html under Products > Optical and Wireline > Ethernet access

5.1.4 The need for standards

With the default assumptions, the difference in recovered cost between the Base scenario and the WDM PON scenario is approximately GBP12 (53%) per line per month. This assumes a significant reduction in the cost of WDM PON equipment (OLT, splitter and CPE) over the modelling period. However much of the roll-out occurs early on, before the majority of this decline in costs has occurred. To account for this, we also considered a sensitivity test in which the market waits for WDM PON costs to bottom out before deploying a network (see *Timing of WDM deployment* in Section 4.5). By delaying deployment in this way, the cost difference between the Base and WDM PON cases reduces to approx GBP7 (32%) per line per month.

In fact, the increased cost in the WDM PON scenario is not a cost of competition, but a 'cost of innovation': consumers would have to pay GBP12 in the near term (or GBP7 if they wait) for the added benefits of WDM PON technology. As discussed earlier, these benefits would include having a choice of the download rates delivered to the home, and potentially lower prices from dynamic traffic management.

It should be noted that both of these cost differences are based on an assumed reduction in the cost of WDM equipment. This depends on there being scale economies from volume production of such equipment, and in this respect standards will play a key role in facilitating the successful deployment of WDM. This includes the wider deployment of WDM OLTs for residential purposes (at present there are some limited examples of WDM being used for access networks for the *business* market) and the development of residential WDM line-termination CPE. Standards will also facilitate the reduction in the cost of the specialist splitters required for WDM (arrayed waveguide grating). These splitters are currently around 14 times the cost of a GPON equivalent. In summary, standards development will be essential to reduce the cost of WDM access networks and enable their successful deployment. WDM PON standards are not expected to be finalised before 2013, and the market will need time to adopt the standards and reach volume production of network equipment. Therefore, we do not expect lower-cost, 'mature' WDM PON equipment to be available before 2015–2016.

5.1.5 Avoiding market foreclosure

There are risks that the market could become foreclosed to potential forms of competition in both of the active-electronics scenarios. In the Base scenario, market foreclosure could occur if the available scope for innovation from the layer-2 interface is below what is considered fit-for-purpose. Ofcom has already taken steps to avoid such foreclosure by defining the technical requirements of fit-for-purpose ALA. Continued engagement in the development of ALA will be important to ensure that competition is possible in a retail market that follows the Base scenario.

If WDM is deployed with a solution to manage churn through an ODF, it is unlikely that WDM would have the same risk of constraining innovation as the Base scenario, as operators will have access to the physical layer of the network (the wavelengths of light carried on the PON).

However, if WDM is deployed with an Ethernet-based churn management solution, the risks of foreclosure associated with the Base scenario are equally applicable to WDM PON. WDM PON is likely to be deployed as an upgrade to GPON (although the development of next generation (10G) GPON is ongoing and may provide an alternative), and Ofcom must keep careful watch on the development of ALA and WDM PON. A worst-case scenario is that a form of ALA is developed that is not fit for purpose, and this then becomes the foundation for an Ethernet-managed WDM PON solution. If WDM PON does develop along the Ethernet route (when it is standardised by FSAN), then the precedent set by ALA on GPON will be even more important. If fit-for-purpose ALA is not developed, then Ofcom must consider facilitating the deployment of ODF-managed churn solutions, to ensure WDM can support effective competition.

There are also practical implications of allowing the upgrade from GPON to WDM PON. Changes will be required to three pieces of equipment: line-termination CPE, OLTs and splitters. It is likely that the CPE upgrade will be a straight swap, with the old CPE being exchanged for a new one. The OLT equipment in the exchange will also have to be changed out, and FSAN is considering the development of a programme that will facilitate this upgrade. As the OLTs will be easily accessible in the exchange, there should be few barriers to the equipment there being upgraded. Finally, the splitter will need to be upgraded out in the field. While solutions already exist to replace the standard GPON splitter with a WDM AWG that has the same form factor[23], the splitter needs to be accessible to allow this to be carried out efficiently. In fact, it is likely that the splitter will be located in an accessible location such as a cabinet or footway box to allow for maintenance, so there should be few barriers to this element of the upgrade.

[23] See http://www.adc.com/us/en/Library/Literature/106465AE.pdf

5.1.6 Summary of implications for competition based on active equipment

Implication	*Comments*
Prospects for competition	Low investment requirements should ensure entry by alternative operators, providing that the Base scenario offers the right functionality, and WDM cost reductions can be achieved
BT's potential advantage	BT has advantages due to its control over the existing duct network and access to existing spare fibre. These advantages are likely to be important to create a viable business case for the deployment of a fibre network offering wholesale services. However, it is likely that this type of access will be the only option in some areas, so wholesale prices will require monitoring and potentially regulating
Steps to avoid foreclosure	• Facilitating the successful standardisation of 'fit-for-purpose' ALA and residential WDM PON • Observe development of ALA and WDM PON to understand if Ethernet-managed WDM PON can support effective competition. • Promoting equipment deployment strategies that allow the upgrade from GPON to WDM PON
Specific policy implications	• Monitoring and potential regulation of wholesale prices on active-interface access networks • Consider cost-benefit of line-termination CPE being replaced with each churner

Figure 5.1: Implications of competition based on active equipment [Source: Analysys Mason]

5.2 Unbundling based on passive infrastructure

5.2.1 The best flexipoint option

In addition to unbundling based on active electronics, we also considered options that use fibre flexipoints to manually switch users between different GPONs, and allow competition based on access to passive infrastructure. In terms of the cost of competition, the modelling showed the 'Field Flexipoint, Multi Fibre' scenario to be the optimum model for passive GPON unbundling.

In terms of the **incumbent** breakeven test, the modelling showed the 'Field Flexipoint, Multi Fibre' scenario to be marginally better than the 'Single Fibre' scenario. These two scenarios are very similar, with the lower fibre count in the final drop of the single fibre scenario being offset by the need to visit the flexipoint when a customer churns – a cost which is not incurred in the multiple fibre scenario. As revealed by our interviews with operators, the choice between these two options may be influenced by the operator's business model. If an operator already sends an engineer out to the home to install equipment for each new customer, then visiting the flexipoint may create little incremental cost, but if it sends out the line-termination CPE to new customers to self-install, then the 'deploy-and-forget' approach involved in the multiple-fibre scenario may be more suitable.

In the breakeven tests for an **altnet**, the two 'Field Flexipoint' scenarios were also relatively similar in terms of viability. However, for an altnet the 'Exchange Flexipoint, Single Fibre' scenario appears to be a highly viable option for passive-infrastructure competition in certain geotypes. This is an interesting result, as this scenario effectively involves a point-to-point network between the exchange and the home. It is attractive to an altnet as it enables the operator to share the cost of fibre: there is a single fibre to each home, and in order to allow customers to churn freely between operators, we have assumed that the deployment cost and subsequent ownership of each fibre is effectively shared between the operators in the retail market. This fibre sharing has two advantages for altnets: they effectively only have to provision fibre for their own share of the market (as opposed to passing all homes in the deployment area, as assumed in the other scenarios), and we assume they do not need to deploy any sub-duct.

One of the drawbacks of a point-to-point network is that more fibre is deployed compared to PON, and therefore more new duct must be built. We have assumed that any new duct costs will be borne by the incumbent, and that the altnet simply rents any space used by its share of the fibre. In reality, altnets are unlikely to be able take advantage of the 'Exchange Flexipoint, Single Fibre' scenario as modelled in this study, because the incumbent is unlikely to be willing to meet the costs of deploying all the new duct to accommodate the amount of fibre needed for a point-to-point network.

As discussed above, the difference in viability between the 'Field Flexipoint' options is relatively small, and therefore we will consider both the 'Field Flexipoint, Multi Fibre' and 'Field Flexipoint, Single Fibre' options for passive-infrastructure-based competition using GPON networks.

In all of our analyses, the 'DP Flexipoint, Single Fibre' scenario was shown to be the least viable and therefore is not likely to form a suitable basis for passive-access competition. This lack of viability arises from the high capex costs of deploying numerous small flexipoints, and the high opex costs of visiting them at their disparate locations.

5.2.2 Practicalities and scope for innovation

Deploying a GPON access network with a flexipoint in the field and a single fibre per home would divide the network into 'duplicative' and 'shared' sections. The network between the exchange and the first ODF of the flexipoint will be 'duplicative'. We have assumed that each operator will deploy enough fibre up to the cabinet to each pass all homes in the deployment area. Given that fibre cables from different operators will be running in parallel in this part of the network, each operator will deploy its fibre within its own separate sub-duct. At the flexipoint, each operator will deploy its own ODF (on the exchange side) to terminate its own fibre.

From the flexipoint to the home, the network will be 'shared'. Immediately after the operators' ODFs, a shared ODF will connect to the single fibre that connects to each home. Access rights to this part of the network will need to be equal between all the operators in the market. There are a number of models for how this part of the network could be deployed, and how access to it could be managed.

- It could be deployed and managed by a single player (e.g. the incumbent). Once deployed, that player would rent access to the shared ODF and terminating fibres on a regulated equivalence basis to all operators. Further regulation might need to be applied to the wholesale cost of that access.
- A variant of this model is for different operators to own the shared ODF and terminating fibres in different areas of the country. Under this model, there may be scope to encourage investment by allowing the deploying operator exclusive access to the local customer base for a certain time after deployment.
- Finally, the shared part of the network could be deployed and managed by a dedicated third party. Having separate ownership of the shared parts of the network would also allow that owner to manage any changes in connection as customers migrate onto fibre and between operators. This would also enable efficient management of connections, rather than both the 'losing' and 'gaining' operator each visiting the flexipoint to disconnect/connect a churning customer. Also, there may be scope to implement new connection techniques, e.g. remotely controlled mechanical connection changers.

An important practicality of the 'Field Flexipoint, Single Fibre' scenario is providing accommodation for the ODFs. This is likely to be done in a street cabinet, allowing easy access in order to connect new customers and disconnect churners. It will be most efficient to include the cabinet along with the other shared infrastructure (fibre and ODF), otherwise multiple cabinets will be required: one for each operator's ODFs, and another for the shared ODFs. Despite only using a single cabinet to house multiple ODFs, a flexipoint deployment is likely to encounter significant issues with finding space and planning permission to deploy this new cabinet. Although GPON deployments are currently only being considered in areas where FTTC is not being deployed, a situation may arise in which a GPON flexipoint is deployed next to an FTTC cabinet *and* an existing PSTN cabinet. There may be a role for regulatory policy to encourage the deployment of derived voice products to avoid such three-cabinet scenarios from happening. Note that having a shared cabinet will require standardisation of the ODFs that are installed inside it.

The 'Field Flexipoint, Multi Fibre' scenario will also feature a duplicative network architecture between the exchange and the flexipoint. As with the 'Single Fibre' configuration, we have assumed that each operator will deploy enough fibre to pass all homes in a deployment area, and that sub-duct will be needed to separate the cables of different operators. At the flexipoint, each operator will deploy its own splitters to connect the fibre running from the exchange to the terminating fibre connecting the customer's home.

Unlike the 'Single Fibre' scenario discussed above, the terminating segment of the 'Field Flexipoint, Multi Fibre' scenario could be *either* shared or duplicative. In theory, it would be possible for the terminating segment to remain duplicative, with each operator deploying its own fibre cable to each home. This would effectively create a fully parallel PON infrastructure, with each operator fully duplicating the entire access network. However, this configuration is likely to be impractical, as it requires sub-duct all the way to the home and multiple fibre cables being terminated in each customer's premises. A more efficient configuration would be to have a shared architecture in the terminating segment. In this case, a single cable would be laid to each home, with (for example) four fibres. Operators would have shared access to the cable, and each would connect their exchange fibres to one of the fibres in the cable. As described in our market review,[24] this model is being proposed in Switzerland, France, and a number of other countries.

A shared terminating architecture such as this has significant advantages: it negates the need for sub-duct and requires only one cable to be installed and terminated at the customer's home. However, operating a shared architecture brings the same management challenges at the 'Single Fibre' scenario, and the same three options exist for ownership/control of the terminating segment (namely: incumbent, 'first in' operator, or independent body). Furthermore, there is the question of how many fibres to include in the terminating segment. Part of the appeal of this scenario is that once the fibre is installed, it requires little further operating expense to change over customers. Therefore, enough fibres should be installed up-front to allow all potential operators in an exchange to have access to end customers. As we note in our assumptions for the cost modelling, the size and cost of fibre cable is relatively flat up to around eight fibres. It may make sense, therefore, to install the maximum number of fibres for this base cost to ensure the terminating segment does not unnecessarily constrain the number of operators that can be active in an exchange area. In order to realise the full 'deploy and forget' benefits of the multi-fibre scenario, it should be ensured that when a customer is first connected at the flexipoint, they are passively connected to all of the operators present at the flexipoint, ready to receive future services. From a splitter provisioning viewpoint, operators must be aware that this approach will mean that spare capacity on their own splitters will be used up when their competitors first connect up a customer.

The final practicality for the 'Field Flexipoint, Multi Fibre' scenario is accommodating the splitters at the flexipoint. Unlike the single-fibre scenario, fibres do not need to be re-connected each time a customer joins or leaves the network, and therefore the space required in the flexipoint is much less. It will still be important that the flexipoint is located in an accessible location, to allow maintenance and access to the terminating fibre: we have suggested that the flexipoint could be located in an existing footway box. In the modelling, we have assumed that there will be enough space in all but 10% of existing footway boxes. This frequency will be dependent on the number of operators active in an exchange: the more operators need that need to deploy splitters, the higher the likelihood that existing boxes will need to be upgraded to accommodate them all.

In both of the flexipoint scenarios discussed above, line-termination CPE is likely to be replaced as customers churn, as the incumbent will not have control of a complete access network and therefore will be less concerned about policing the devices that are connected to it (compared to the Base or WDM PON scenarios).

24 See Analysys Mason's report *GPON Market Review: Competitive Models in GPON: Phase 1*, 26 October 2009 (ref: 15340-442)

Allowing operators access to the passive infrastructure gives them a significantly greater scope to innovate, compared to the Base and WDM PON scenarios. All operators will be able to exert complete control over traffic management and the bit rates supplied to customers, and will also control the capacity of their PON and the schedule with which any equipment upgrades are made. Further, they will be able to deploy resilient fibre routes up to the flexipoint, and even vary their choice of architecture (perhaps deploying a point-to-point network in some cases). Finally, operators will have a greater scope for setting the level of their pricing, as the only wholesale product they will buy will be access to the terminating fibre beyond the flexipoint.

5.2.3 The cost of innovation and competition

As with the WDM PON scenario, there is a cost to the consumer for the increase in scope for innovation that is provided by the flexipoint scenarios (over the Base scenario). However, compared to the WDM PON scenario, there is also a greater effect from the presence of more than one operator in the retail market (the cost of competition). In the flexipoint scenarios, the cost difference from the Base scenario comprises both a cost of innovation and a cost of competition. These costs are inherently linked, as these types of architecture would only be deployed in a competitive market. Therefore the components of these costs must be considered together.

For the ‘Field Flexipoint, Single Fibre’ solution in a retail market with three operators, the recovered cost per line per month increases by GBP10.78 (48%) compared to the Base scenario. This increase consists of the following cost components:

- duplication of OLT capacity (incurring both equipment capex and power/accommodation opex) [GBP0.70]
- deployment of flexipoint (ODF and cabinet) [GBP1.83]
- duplicate fibre between the exchange and flexipoint [GBP0.20]
- sub-duct between the exchange and flexipoint [GBP0.76]
- flexipoint connection [GBP5.81]
- additional duct maintenance due to allowing altnets to access duct [GBP0.67].

The total increase of GBP10.78 per line per month represents a significant premium over the Base scenario in order to support competition with a large scope for innovation. However, there are a number of factors and efficiency measures that would be likely to reduce this figure:

- Our assumptions for the cost of flexipoint ODFs and cabinets are based on industry benchmarks, but these costs may fall due to volume production and bulk-buy discounts.
- We have modelled separate installation costs for sub-duct (GBP3 per metre) and fibre (GBP8 per metre), but in reality these two assets would probably be installed at the same time, resulting in a capex saving.

- We have also modelled separate costs for an operator visiting a flexipoint to connect new customers and disconnect churners, but in reality disconnection and connection could probably be done in the same visit, resulting in an opex saving.
- Finally, we have assumed that no two customers will connect or churn at the same flexipoint on the same day. This is a likely scenario, but there may be some scope for aggregation of customer connection visits, creating a further reduction in connection costs.

For the 'Field Flexipoint, Multi Fibre' scenario in a retail market with three operators, the recovered cost per line per month increases by GBP5.16 (23%) compared to the Base scenario, significantly less than in the single-fibre scenario. This cost includes the following components:

- duplication of OLT capacity (incurring both equipment capex and power/accommodation opex) [GBP0.70]
- deployment of flexipoint (splitter duplication and footway box upgrade) [GBP0.75]
- additional civil works and duct deployment between flexipoint and home [GBP1.52]
- duplicate fibre throughout the access network [GBP0.92]
- sub-duct between the exchange and flexipoint [GBP0.76]
- flexipoint connection costs [GBP0.24]
- additional duct maintenance due to allowing altnets to access duct [GBP0.27].

Crucial to the difference in costs between the flexipoint scenarios is the absence of the high flexipoint connection costs in the 'Multi Fibre' scenario. This is because once the network is deployed, it is assumed that the customer can take care of any reconnection activity by swapping their line-termination CPE (either existing or newly provided) onto the correct fibre installed at the home. However, this assumption may be optimistic, and in reality an engineer may need to visit the home to carry out this operation, at least in some cases. Also, our assumption that only 10% of footway boxes would require upgrading to accommodate multiple splitters could prove to be conservative: in reality a greater proportion of boxes could require an upgrade which would increase costs. Finally, we have assumed that connections to splitters at the flexipoint would be done as customers take services. An alternative deployment strategy would be to fully pass and connect up a deployment area by connecting up all lines to the splitters. Given the uncertain nature of NGA business cases, we believe that most operators will seek to minimise their up-front investment and therefore our modelling approach is reasonable. If operators do decide to fully provision and connect splitters up-front, then this would increase costs, and therefore the amount recovered each month from each customers.

The reality of a deployment could see the flexipoint cost components become more significant for the 'Field Flexipoint, Multi Fibre' scenario, increasing the cost premium for the multi-fibre option compared to the Base scenario beyond the current figure of GBP5.16.

In summary, there is scope for the cost of competition for the flexi-point scenarios to become more similar. The cost for the single-fibre scenario could come down with efficient flexipoint management and economies of scale on flexipoint equipment. Conversely, the cost for the multi-fibre scenario could increase if changing operators requires an engineer to visit the home and a greater number of footway boxes require upgrade.

5.2.4 Feasibility and the extent of a deployment

As noted in the introduction, this study is indicative and does not consider all the cost components of deploying and operating a GPON network, e.g. backhaul from the exchange and retail product support. However, the cost outputs from the model do compare well with the proposed pricing from Openreach for FTTP GEA. For all coverage levels considered (25%–100% of an exchange area), the recovered cost per line per month for the Base scenario is around GBP22. This compares well with Openreach's GEA pricing of GBP20 per month for the 30Mbit/s peak rate product and GBP25 for the 100Mbit/s product. We believe that the costs which were not considered represent a small additional cost per line, and therefore the breakeven analysis gives an indication of the likely extent of a GPON deployment.

Our analysis suggests that a viable 10-year business case can be created by an incumbent deploying either of the field flexipoint architectures if it achieves a 50% share of the non-cable NGA retail market. The modelling also assumes a strategy of 100% population coverage within an exchange, selective deployment to dense geotypes, and the use of innovative ducting techniques to raise duct re-use to a high level.[25]

An altnet can also create a viable ten-year business case using either of the field flexipoint architectures, if it achieves around a 50–60% market share of the non-cable retail NGA market.

It should be noted that achieving 50–60% of the non-cable retail NGA market will be a significant challenge in the context of the UK's competitive broadband market, and both the incumbent and the altnets may limit their roll-outs to the more profitable geotypes. This need for market share may be mitigated by operators offering wholesale access to their deployed network, or if retail and wholesale prices can rise to higher levels than we have considered, but the effects of this additional income have not been considered in our modelling.

5.2.5 Avoiding market foreclosure

The investment requirements for competition based on passive infrastructure are significantly higher from an altnet's point of view than for that based on active equipment. Therefore, actions to avoid the market becoming foreclosed to competition are focused on reducing these investment barriers. We have already discussed measures that could reduce the costs of the 'Single Fibre, Field Flexipoint' scenario (Section 5.2.3). Shared investment schemes could be beneficial to both flexipoint scenarios by reducing the amount of duplicative infrastructure, increasing asset

[25] Pricing remains flat as in the default set of assumptions.

utilisation and reducing operating costs. An example of shared investment could be sharing the cost of deploying the fibre and sub-duct to pass the required number of homes in an area.

For the 'Field Flexipoint, Multi Fibre' scenario, it may also be important to ensure that any GPON roll-out includes a multi-fibre cable being installed in the terminating segment to each home. Even if there are no competing operators at the time of deployment, it would be prudent to install a multi-fibre cable which would support flexipoint-based competition in the future, especially as the materials cost is little more than for a single fibre. If GPON is deployed with single-fibre terminating cables, then this could foreclose the market to competition based on the multi-fibre scenario, as upgrading the cable to multi-fibre would incur significant additional cost.

5.2.6 Summary of implications for competition based on passive infrastructure

Implication	*Comments*
Prospects for competition	Prospects for competition could be more marginal than for unbundling based on active equipment (due to higher investment requirements for altnets), but could be achieved in certain geotypes with the right strategy and sufficient market share
BT's potential advantage	Under full infrastructure competition, BT has a significant advantage due to its access to existing duct and fibre infrastructure.
Steps to avoid foreclosure	• Promotion of efficient processes to reduce opex costs, and shared investment to reduce capex costs • Installation of multiple-fibre cables in the terminating segment, to provide possibility of competition based on the 'Field Flexipoint, Multi Fibre' scenario
Specific policy implications	• Regulated access to terminating fibre • Facilitating standardisation of flexipoints (ODF accommodation) to allow cabinet sharing under the 'Field Flexipoint, Single Fibre' scenario

Figure 5.2: Implications of passive-infrastructure based competition [Source: Analysys Mason]

5.3 Practical implications of PON deployments

5.3.1 Availability of existing duct

The availability of existing duct has a significant effect on the recovered cost per line per month. By applying different assumptions regarding the level of available duct, this cost for the Base scenario varied between GBP27 ('low' duct availability) and GBP15 (using a selective deployment strategy of only choosing those ducts which have availability). It should be noted that the levels of availability in the selective deployment scenario (assumed to be 95% in all parts of the network) will only be achievable for partial roll-outs, such as the 25% coverage assumed in the default scenario set. As coverage levels increase, the duct re-use levels achieved will reduce: our 'medium' duct re-use assumption has a re-use level of between 80% and 30% depending on the section of the network.

In all scenarios, duct and civil works are the largest cost components, together representing 37% of the recovered cost per line per month in the Base scenario, and 35% in the 'Field Flexipoint, Multi Fibre' scenario. Therefore, regulatory policy could usefully focus on reducing duct and civil works costs through the promotion of innovative techniques and processes. Some of these have already been explored as part of Analysys Mason's sample survey of duct access for Ofcom[26], and include:

- development of engineering rules to ensure efficient use of available space
- exploring innovative fibre and duct deployment techniques
- development of a governance model to administer available duct space
- definition of KPIs to track performance in the duct access process
- training of field forces to a minimum level of competency
- digitisation of network plans and duct records.

The duct availability assumptions in the model are varied between scenarios to take account of different levels of fibre being deployed. For example, for the 'Field Flexipoint, Multiple Fibre' scenario we reduced the duct availability in the terminating portion of the network to take account of the higher levels of fibre being deployed. However, the modelling did not take account of duct availability reducing as more operators deploy their own fibre. This issue will become especially relevant if operators do each deploy enough fibre to pass all homes, as we have assumed in the modelling. Therefore, in areas where there is marginal duct availability there could be a significant first-mover advantage. Also, if the first operator to deploy fibre in an area does so inefficiently, there is a risk that the market in that area could become foreclosed to additional operators deploying fibre and competing on an infrastructure basis. Promoting innovative techniques and process as described above would mitigate this risk.

5.3.2 Impact of split ratio

With our default assumption set (including NGA coverage of 25% of households within a geotype), the modelling showed that doubling the split ratio of the PON network had a variable impact on the recovered cost per line per month. In the Base scenario, the difference between the GPON split being 1:64 and 1:128 was just GBP0.45 (2%) per line per month. This small difference is due to the limited extent of roll-out, which means that many OLT cards are already under-utilised (the penetration on each PON is low), and so increasing the split ratio has little effect. However, as coverage levels are increased and OLT card utilisation improves, the effect of the split ratio becomes larger. Indeed, for the WDM PON scenario, in which each OLT card holds just 32 users (compared to 640 for GPON), doubling the split ratio to 1:64 reduces the cost per line per month by GBP2.89 (8%).

26 See http://www.ofcom.org.uk/telecoms/discussnga/duct/ductreport.pdf

In terms of regulatory policy, there is likely to be little need for intervention in increasing the split ratio of PON networks: the industry will naturally move towards the optimum ratio as operators seek to increase the number of users they serve for a given expenditure, and vendors seek ways to differentiate themselves from competitors by addressing this need. One area of regulatory concern could be increasing the number of users that are dependant on a single piece of exchange equipment (in the scenario with the maximum split ratio, for example, 1280 GPON users could potentially be connected to a single OLT card). While any equipment failure and associated service outages could be little more than an inconvenience for broadband connections, there could be more serious implications if the market moves towards fibre-based derived voice products, e.g. for ensuring access to emergency services.

5.3.3 Impact of long-range PONs

While the modelling did not specifically consider the introduction of long-range PONs, this could be an important development in the use of fibre in the access network. The FSAN 10G GPON standard is currently in development and will extend the reach of a GPON from 20km to 60km. As noted in our review of GPON technology,[27] this increase in range will allow a greater area of housing to be served from a single exchange, allowing a reduction in the number of operational exchanges and any associated opex. In urban areas, the number of users that can be served from a single exchange will be constrained by the ability to terminate large amounts of fibre at a single location, and so developments in long-range PONs will bring more benefits to less dense rural areas.

If long-range PONs are planned for deployment in rural areas, and there is an associated reduction in the number of operational exchanges, BT's 'sale and leaseback' agreement with Telereal will have to be considered. Under the terms of the 30-year agreement (signed in 2001), BT may only vacate a certain percentage of properties each year without penalty.[28] If the deployment of long-range PONs to rural areas becomes a viable strategy for delivering NGA services to these households, then Ofcom may need to consider what restrictions the Telereal agreement places on this deployment. Overall, while long-range PONs may be a viable solution for rural deployment, the current commercial agreement that BT has may mean that the case for moving to this solution is not as attractive as it could be in other countries.

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27 See *GPON Market Review: Competitive Models in GPON* , July 2009

28 See http://www.landsecurities.com/press.asp?PageID=25&MediaID=23&InitialView=False

5.3.4 Summary of practical implications of PON deployments

Implication	*Comments*
Prospects for competition	See previous comments on active- and passive-based competition
BT's potential advantage	With control over much of the duct network, BT could take advantage of marginal duct availability, leaving no space for other operators
Steps to avoid foreclosure	• Promote efficient use of existing duct space
Specific policy implications	• Engage in the development of innovative techniques and processes for use of existing duct • Consider any implications of increasing split ratio for access to emergency services • Consider whether BT's agreement with Telereal would adversely impact the use of long-range PONs to deliver NGA services to rural areas

Figure 5.3: Practical implications of PON deployments [Source: Analysys Mason]

5.4 Other policy considerations

5.4.1 Impact of extent of roll-out and level of take-up

The extent of the NGA roll-out has only a limited effect on the cost of competition: for the Base scenario the recovered cost per line per month varies between GBP22.35 at 25% coverage within a geotype, to GBP22.07 at 100%. The difference is only small because it is only the first portion of the network (section A in our network breakdown) for which duct and fibre costs are incurred, regardless of the level of roll-out. All other network and equipment costs scale with the level of roll-out.

Despite this limited impact on costs, coverage levels do have a significant effect on the viability of the business case, due to the impact of increased revenues from a larger customer base. It should be noted that BT's proposed policy of only rolling out to 25% of the market is likely to take advantage of a selective deployment in areas of favourable duct availability. The modelling shows that this strategy could reduce the cost to GBP15, which is well below the proposed wholesale price for GEA.

The level of NGA take-up has a much greater impact: in the Base scenario the recovered cost per line per month varied from GBP33 where take-up only rises to 19% of non-cable broadband users in 2019, to GBP18 where take-up reaches 93%. Take-up has a significant effect on the results because it affects the number of end users across which to share fixed costs, such as the cost of passing all homes with fibre and any associated duct costs. In terms of delivering low-cost NGA services to consumers, regulatory policy should consider in detail the expected level of take-up, and it will be essential for Ofcom to understand BT's available strategies to encourage take-up. Ofcom will therefore need to engage with BT on a detailed business-planning level, to validate the results of the modelling.

5.4.2 Presence of FTTC (a mixed fibre economy)

We also considered the impact of deploying FTTH PON in the context of a FTTC VDSL deployment. In this case, we assumed that any duct installation costs would be shared between the two infrastructures in the portion of the network up to the cabinet, and in proportion to the number of lines that each technology would cover. In the presence of FTTC, the cost per line per month was GBP0.70 less in both the Base scenario and 'Field Flexipoint, Multi Fibre' scenario, compared to when no FTTC network was present.

Although the sharing of duct deployment costs is the dominant feature of a mixed-fibre network (and was the only effect modelled in the present study), there are other synergies and potential cost savings that could occur. Greater economies of scale in fibre cable could be realised in the first part of the network, as the two technologies could utilise different fibres of the same cable. Also, systems and processes that are developed for FTTC could be leveraged for FTTH, especially if the FTTH deployment includes a cabinet-type flexipoint. For example, both technologies are likely to require a visit by an engineer to connect new customers, and the same process could be used to schedule and manage those visits for both technologies. Regulatory policy could aim to promote synergies such as this across the technologies, with the aim of keeping costs low and helping deployments go further.

5.4.3 Comparison with FTTC costs and sub-loop unbundling

A comparison with the results from our BSG costing work on fibre deployment shows that FTTC is significantly cheaper than all of the FTTH PON scenarios considered in the present study, on both a per-home-passed and per-home-connected basis: under the Base scenario, FTTC is around 25–30% of the cost of a FTTH PON deployment. This result is not surprising: an FTTC cabinet deployment makes use of the existing copper network in the lengthy section of the network beyond the cabinet, whereas an FTTH deployment must replace this copper with fibre. What is more interesting is that although the SLU product offered by BT has been available for some time, no alternative operator has yet taken advantage of this. The 'Field Flexipoint, Single Fibre' scenario is very similar to a sub-loop unbundling model, and given the higher capex costs, this may mean that operators cannot make this business model work either (this outcome is reflected in the our altnet breakeven tests).

However, there are key differences between the conventional copper-SLU model architecture and the PON 'Field Flexipoint, Single Fibre' architecture. First and foremost is the fact that the PON flexipoint will be passive, thus avoiding the practical issues of a VDSL cabinet which requires significant amounts of power to run and cool the DSLAMs that it houses. Although the PON flexipoint cabinet will still have to be visited each time a customer connects to a new service, unplanned maintenance visits should be minimal compared to a VDSL cabinet, which is filled with electronics.

Also, fibre in the terminating link provides a much higher bandwidth capability than copper, allowing a greater range of services to be delivered, and operators can be confident of being able to offer premium services (with the right equipment upgrade) for many years to come, and extend their business case (and therefore repayment period) over longer timescales. This second point is applicable to all PON architectures, when compared to SLU. Engagement with industry on the practicalities of a flexipoint deployment, and how this compares with SLU, would bring additional insight into the feasibility of the passive unbundling of PON infrastructure.

5.4.4 Impact of geotype

The cost of competition and innovation varies significantly by geotype. In London, there was a GBP3 (24%) difference in recovered cost per line per month between the Base and 'Field Flexipoint, Multi Fibre' scenarios. This difference was higher in other geotypes, and was greatest in the '>10k lines (b)' geotype where it reached GBP8 (22%) per line. The cost of competition and innovation increases in less densely populated areas as average line lengths increase and the cost items associated with multiple operators and line length also increase (e.g. duplication of fibre, installation of sub-duct).

The measures described above to reduce the cost of flexipoint-based competition (see Section 5.2.3) will be even more important in low-density areas. Operators may wish to offer consistent prices across different geographies, but the large cost variations may prevent this, resulting in the prospect of geographic pricing that could be more pronounced than it is today. By pursuing initiatives to reduce the cost of competition, Ofcom could promote widespread NGA deployment, and mitigate against large pricing variations by geography.

It should be noted that the geotyping approach used in the modelling does not allow for detailed testing of the specifics of deployment on a sub-geotype level. Examples of these specifics include replicating the doughnut-style deployment proposed by BT[29] (i.e. deploying PON to homes that are either very close to or very far from the exchange) or optimising the placement of splitters based on the size of multi-dwelling units. Additional detailed work to complement this study may be useful in fully understanding the impact of such deployment specifics.

5.4.5 Impact of duct rental income

The breakeven calculation for the incumbent shows that renting access to duct could provide a useful supplementary income in a market with many competing players. The impact of including duct revenue was significant, but our modelling results should be treated with caution. Our duct price assumption is based on an industry benchmark, but in reality duct pricing is very dependent on utilisation and how costs are recovered across participating operators. Also, it is unlikely that many routes will be a straightforward 'single run', so operators may only do this in certain areas. It

29 http://www.openreach.co.uk/orpg/products/nga/downloads/Slide_deck_OFAF_16_April_2009%20final.pdf

is recommended, therefore, that Ofcom take steps to explore in more depth the implications of duct rental for the UK.

5.4.6 Carbon footprint and impact on the environment

The carbon footprint[30] of GPON unbundling will vary by scenario. For example, the carbon footprint of the 'Field Flexipoint, Single Fibre' scenario (where a technician must drive out to the flexipoint each time a customer churns) will be far higher than that of the 'Field Flexipoint, Multi Fibre' scenario (as visits to the flexipoint are only required to provide initial connection). The base scenario would have the lowest carbon footprint as all churn is managed electronically, while the 'DP Flexipoint, Single Fibre' scenario is likely to have the largest footprint due to the need to visit numerous disparate locations. Ofcom may need to consider the impact on the environment of each unbundling option, when making policy decisions with respect to GPON unbundling.

5.4.7 Summary of implications

Implication	*Comments*
Prospects for competition	See previous comments on active- and passive-based competition
BT's potential advantage	None
Steps to avoid foreclosure	None
Specific policy implications	• Engage with BT at a detailed business-planning level to understand coverage plans and take-up strategies • Engage with industry on practicalities of flexipoint operation • Consider additional work to understand the specifics of deployment at a sub-geotype level • Explore in more detail a duct rental price that would be appropriate for the UK • Consider the impact on the environment of each unbundling option

Figure 5.4: Implications of other policy considerations [Source: Analysys Mason]

30 Defined as the total set of greenhouse gas emissions caused directly and indirectly by an activity.

Annex A: Model structure and flow

The overall flow of the cost model is shown in Figure A.1, and the functionality of the main sheets is described below.

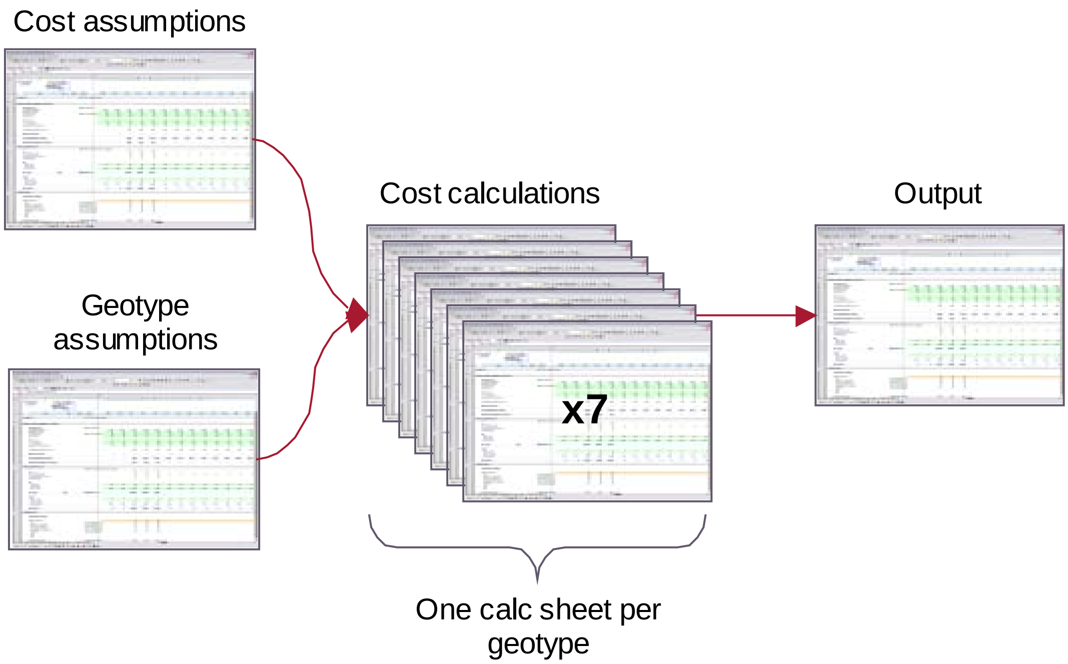

Figure A.1: *Calculation flow of the GPON Excel cost model [Source: Analysys Mason]*

Cost assumptions ('Control' sheet)

This sheet includes all the cost assumptions for the model. These assumptions, which are discussed in detail in Section 3, are grouped under a number of headings: global assumptions (such as network coverage, service take-up and churn), passive unit costs (such as fibre and flexipoint costs), active unit costs (such as OLT and CPE costs), and opex costs (such as power and accommodation charges). The scenarios are also defined in the control sheet, which includes specific assumptions for each scenario. Sensitivities are controlled from the output sheet.

Geotype assumptions

This sheet includes geotype data and assumptions for geotypes covering the whole of the UK (although only seven are used in the modelling). The key inputs to the model from the geotype sheet include numbers of households (houses and multi-dwelling units), network dimensioning (numbers of exchanges, cabinets and distribution points), line lengths and duct availability.

Cost calculations

There are seven cost calculation sheets; one for each geotype modelled in this project. Each calculation sheet produces deployment and operating costs for both an incumbent and an altnet for a single unbundling option and market share. For the purposes of calculating the cost of competition, it is assumed that the incumbent and each of the *n* altnets each have an equal share of the retail market.

We assume that an incumbent and altnet will incur a similar set of network costs, except that the incumbent incurs all duct-related costs and the altnet does not incur any.

Each sheet also calculates a net cash flow (revenue minus costs) for either an incumbent or altnet deploying and operating a network with a given retail market share in that geotype. The cash flows are used in the breakeven analysis.

Output sheet

The output sheet collects the costs from the calculation sheets. Network costs are used to calculate the cost of competition by summing the costs incurred by the incumbent and *n* times the costs incurred by altnets (where *n* is the number of altnets). For example, the total cost of a UK deployment with three operators comprises the incumbent's deployment costs, plus two times the deployment costs of an altnet, as shown in Figure A.2.

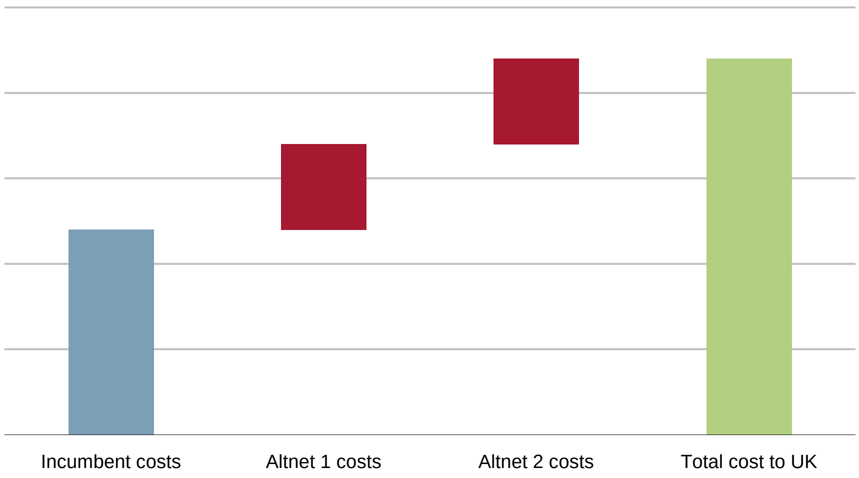

Figure A.2: Example of total UK cost [Source: Analysys Mason]

We use the Excel TABLE() function[31] in the output sheet to produce results for all unbundling scenarios and a variety of retail market shares or numbers of operators. We also summarise the cash flows from the calculation sheets in order to assess the breakeven point by geotype and determine the financial viability of incumbent or altnet deployments.

The output sheet also includes switches to operate a number of sensitivities, including those around duct re-use, splitter ratio, and uptake of the NGA service.

31 Note: the function has the syntax =TABLE(x,y), where x is the cell which is varied according to the heading row across the top of the table, and y is the cell which is varied according to the heading column down the left of the table.

Annex B: Geotyping assumptions

B.1 Introduction

We have used the same geotyping approach as in our cost modelling work for the Broadband Stakeholder Group.[32] We have chosen to use this existing approach in order to maintain consistency with the BSG work and because we believe it is a robust methodology from which to derive the cost of fibre deployment. We use the size and coverage areas of BT exchanges to divide the UK into 13 geotypes. The cost of deploying GPON will be heavily influenced by the topology of the existing copper network, and therefore it is appropriate to use geotypes based on exchange areas. Only the first seven geotypes are used in the GPON competition cost modelling, covering approximately 66% of homes.

We have only considered residential premises in this cost modelling exercise. We expect that the cost of competition will most directly affect the residential consumer, and while we recognise that business revenue may have an impact on the breakeven analysis, we expect this impact to be small.

We recognise that Ofcom has access to more accurate data on cabinet placement than the estimates provided in this geotyping approach. We have tested the influence of cabinet location on cost and believe that the effect of including Ofcom's data would again be relatively small.

In the remainder of this section, we set out the approach to defining the geotypes. Note: this explanation is adapted from our report for the BSG, and is included here for completeness.

B.2 Geotyping approach

We have used a combination of three parameters to define the geotypes: town size, exchange size and line length.

The exchanges of highly populated areas, such as major urban areas, were segmented first. It is likely that these areas will have the lowest costs of deployment, and will be the first to receive next-generation broadband services during a roll-out. As such, they have been identified separately from the rest of the country. The exchange areas that cover these large urban areas were identified manually.

[32] See Analysys Mason's report for BSG, 'The costs of deploying fibre-based next generation infrastructure', available at http://www.broadbanduk.org/component/option,com_docman/task,doc_download/gid,1036/

The rest of the country was divided into areas that could be categorised as belonging to a particular geotype based on the size of the exchange, and the distance of each premises from the exchange.[33] Exchange size has been used as it is related to both the size and population density of settlements. Exchanges tend to cover both the central core of a settlement, and the wider areas of sparse settlements. To reflect this, we have defined a sub-division into 'a' and 'b' geotypes (based on distance from exchange) in those geotypes that are primarily based on the number of lines per exchange. This concept is illustrated in Figure B.1.

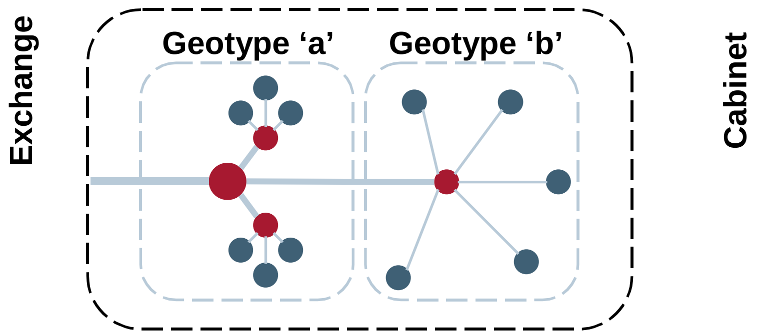

Figure B.1: Different geotypes within an exchange area [Source: Analysys Mason for BSG]

The cut-off distance between the central cluster, and the outer sparse region was chosen by examining typical exchanges on a map. The following sections provide more details on the approach we have used to assign geotypes to exchange areas.

B.2.1 City geotypes

The first three geotypes were assigned to exchange areas covering (a) the urban extent of Inner London, (b) major cities (areas with >500 000 population) and (c) cities (areas with >200 000 population). Inner London exchange areas are defined broadly as the area enclosed by the North and South Circular ring roads. Delivery points within these areas were each assigned to the Inner London geotype. The exchange areas included in the Inner London geotype are shown in Figure B.2 below.

33 Royal Mail delivery points (1.7 million in total) have been used as the base data for where households are located in the UK. We have aggregated the delivery points on an exchange-level basis: each exchange area or portion of exchange area was assigned a geotype, and the delivery points within that area were captured within that geotype. We performed an initial piece of geo-analysis to ensure each delivery point was assigned to its serving exchange. We have assumed that each delivery point has one telephone line.

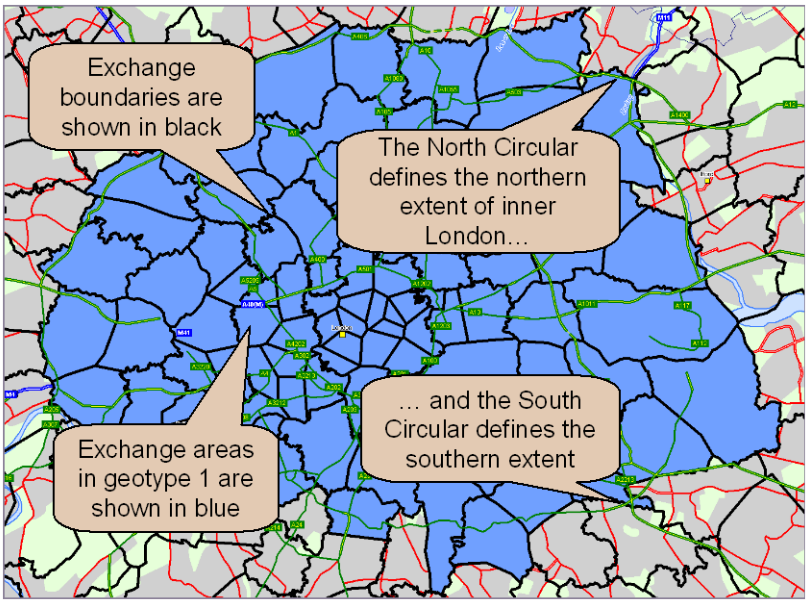

Figure B.2: Inner London geotype exchange areas [Source: Analysys Mason

Major cities (>500k pop.) and cities (>200k pop.) in the UK were also allocated to geotypes by comparing the exchange boundaries with maps of urban areas. The urban areas included in these geotypes are listed in the tables below.

Major city	
Bristol	Sheffield
Glasgow	Newcastle
Manchester	Birmingham
Liverpool	Leeds
Nottingham	

Figure B.3: Major cities allocated to >500k pop. geotype [Source: Analysys Mason for BSG]

City			
Aberdeen	Cardiff	Luton	Southampton
Aldershot	Coventry	Northampton	Southend
Belfast	Barnsley	Norwich	Swansea
Birkenhead	Derby	Plymouth	Middlesbrough
Blackpool	Edinburgh	Portsmouth	Gillingham
Bournemouth	Kingston	Preston	Stoke-on-Trent
Brighton	Leicester	Reading	

Figure B.4: Cities allocated to >200k pop. geotype [Source: Analysys Mason for BSG]

Major cities and cities were allocated to geotypes by comparing the extent of their main urban areas (guided by breaks in the urban sprawl and any ring road) against exchange boundaries. We first overlaid the exchange areas on a map showing major road routes and urban areas, as shown in Figure B.5 below.

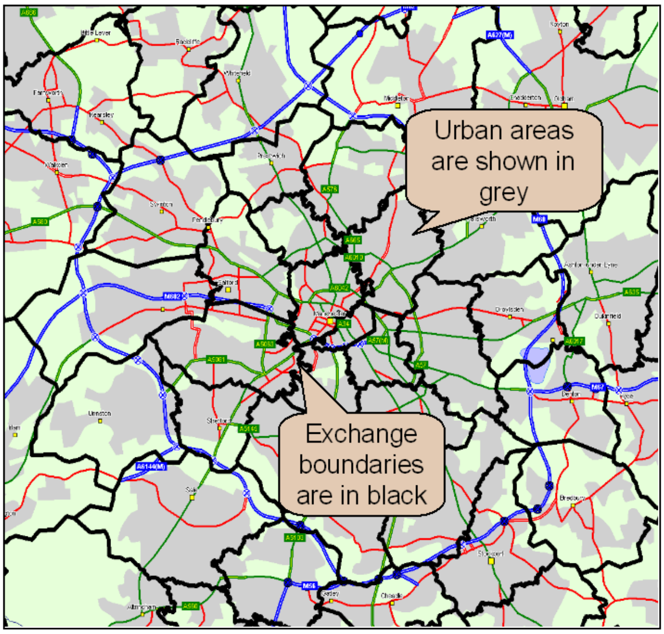

Figure B.5: Manchester urban area with exchange boundaries [Source: Analysys Mason for BSG]

We then manually selected the exchange areas that could be included in the urban area using the map underneath as a guide (Figure B.6). This process was repeated for all major cities and cities.

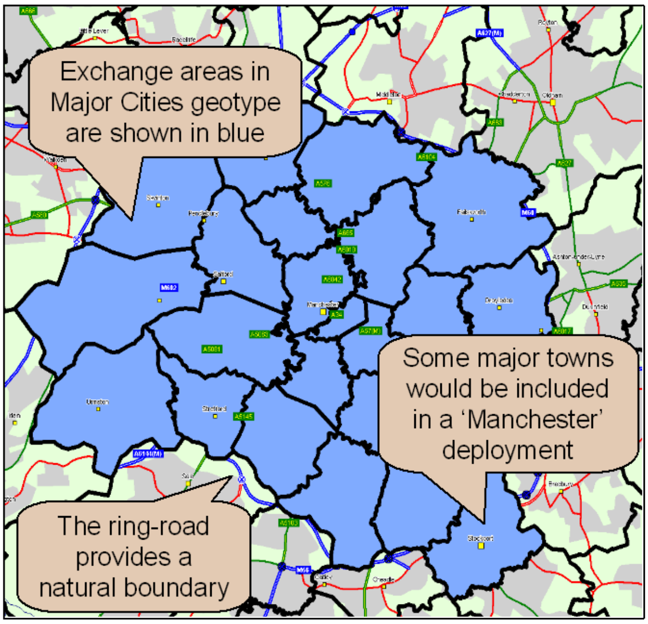

Figure B.6: Manchester urban area with >500k pop. geotype exchange areas [Source: Analysys Mason for BSG]

B.2.2 Other geotypes

Exchange areas outside cities were allocated to geotypes according to the size of the exchange. Within each exchange area, varying levels of clustering are seen and it is important to capture this effect. In order to separately capture clustered and further-out premises, we needed to calculate the distance from each delivery point to its serving exchange. We used the location of every delivery point and every telephone exchange. Using these two data sets, it was possible to calculate the straight-line distance from each delivery point to the exchange.[34] Distances were adjusted before being used in the wider cost model analysis to account for real line lengths being significantly greater than the straight-line distance.

Having derived data on the distances between the delivery point and the exchange, we next defined the criteria to divide premises into the clustered 'a' geotype or the more remote 'b' geotype. These distance criteria were defined by comparing the extent of urban areas within a selection of exchanges to judge an appropriate cut-off. The selection of exchange areas was chosen to compare a range of exchange sizes within the geotype. An example of an exchange area for a medium-sized town, with a boundary between 'a' and 'b' geotypes of 2km, is shown in Figure B.7.

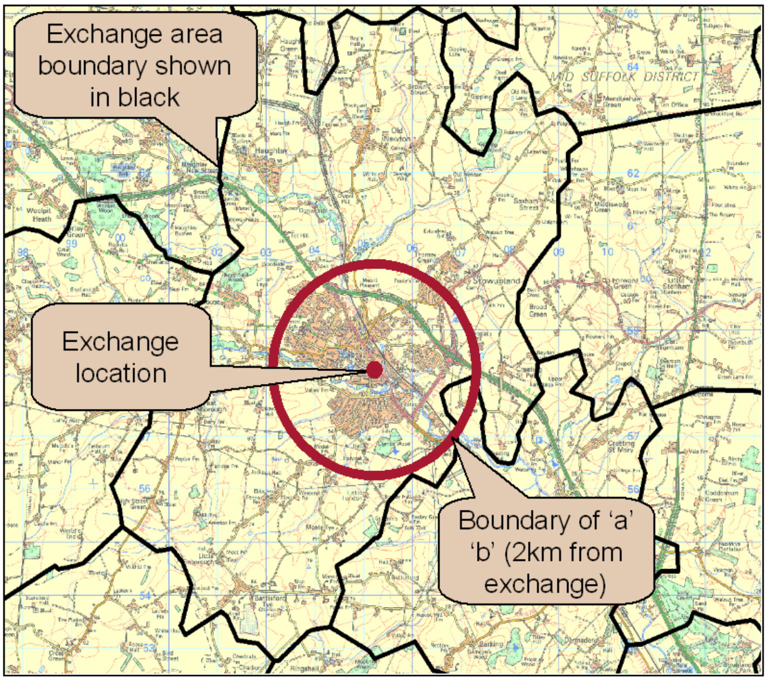

Figure B.7: Stowmarket exchange location and boundary (10 167 lines) [Source: Analysys Mason for BSG] Reproduced from the Ordnance Survey mapping with the permission of the Controller of Her Majesty's Stationery Office © Crown copyright

B.3 Summary of geotypes

A summary of the results by geotype is given in the table below. We have achieved an even spread of premises through careful adjustment of the geotype parameters. This is important to ensure that the costs of deployment can be considered on a gradual basis.

34 This was carried out by undertaking a simple analysis using national grid co-ordinates and did not take into account the curvature of the earth, changes in height along the direct route, or the presence of water. The analysis ensured that distances were based upon the distance to the serving exchange, not the closest exchange.

Geotype	Classification criteria (distances are straight line)	Total number of premises (domestic)	% of UK total premises (domestic)	Avg straight-line distance from exchange to premises (m)	% of total area	Premises density (per sq. km)
Inner London	Inner London	1 335 884	5%	969	0.2%	3641
>500k pop	Major city (pop > 500k)	3 009 074	12%	1391	1.0%	1282
>200k pop	City (pop > 200k)	2 650 705	10%	1410	1.1%	1016
>20k lines (a)	>20k lines, <2km from exchange	2 674 319	10%	1174	0.9%	1360
>20k lines (b)	>20k lines, >2km from exchange	1 688 295	7%	3364	1.6%	453
>10k lines (a)	>10k lines, <2km from exchange	4 129 592	16%	1095	2.1%	854
>10k lines (b)	>10k lines, >2km from exchange	1 495 662	6%	2785	3.4%	190
		16 983 531	**66%**		**10.3%**	

Figure B.8: Geotype summary [Source: Analysys Mason]

The spread of premises across many of the geotypes is relatively even, with the '>10k lines (a)' geotype containing the most premises. The average density of premises decreases with the geotypes, with Inner London being significantly higher than any other. There are significant differences between geotypes, with clustered 'a' areas being much denser than the farther out 'b' areas. It can be seen that, average straight-line lengths are much higher in 'b' geotypes, with most at around 3km.

The key characteristics of the existing BT network are shown for each geotype below.

Geotype	Exchanges	Avg. lines per exchange	Cabinets	Avg. lines per cabinet	Distribution points	Avg. lines per DP	Avg line length (km)
Inner London	86	16 812	2892	500	172 118	8.4	1.24
>500k pop	204	15 512	6329	500	376 721	8.4	1.78
>200k pop	180	15 527	5590	500	332 713	8.4	1.80
>20k lines (a)	167	17 089	6008	475	365 886	7.8	1.50
>20k lines (b)	As in (a)	10 449	4362	400	223 708	7.8	4.83
>10k lines (a)	406	10 728	9679	450	604 925	7.2	1.40
>10k lines (b)	As in (a)	3826	4142	375	215 740	7.2	4.00

Figure B.9: Existing BT network by geotype [Source: Analysys Mason for BSG]

The number of cabinets and distribution points in each geotype has been estimated. The national totals have been calibrated to match data from BT.

Please see the 'Geotype Data' sheet in the Excel model for more detail on the characteristics of each geotype.