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The Determinants of Investment in Very High Capacity Networks: A System Dynamics Approach

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The Determinants of Investment in Very High Capacity Networks: A System Dynamics Approach¹

ITS Biennial June 2021

Cadman, Richard², Curram, Stephan[‡], and Exelby, David³.

Abstract

European regulators of electronic communications markets are under an obligation to pursue widespread access to, and take up of, very high capacity networks, defined as being gigabit capable. Whilst there is an existing body of literature about the relationship between individual regulations and their effect on investment, less research has been conducted that places investment decisions within the market-wide broadband system. This paper seeks to address that gap by developing a generic System Dynamics model and understanding the path specific countries have taken through that model.

The paper highlights a number of drivers of investment, organised around the three elements of the net present value equation: capital, net cash flow and cost of capital. It then develops a high level model before identifying the path to investment found in Ireland and Spain. The paper concludes that determinants of investment in VHCNs are path dependent and thus there is no universal strategy that will work for all countries. Competition is always an important determinant but how firms respond to competition is a function of local circumstances and legacies.

¹ This paper is based on a research project conducted by the authors for the Body of European Regulators of Electronic Communications (BEREC) in 2019. The content of the paper, however, is entirely that of the authors. Thanks are due to the various BEREC members and representatives of NRAs with whom the authors worked during the initial project, The authors also extend their thanks to Richard Carter, Alan Graham and Kim Warren for their input and challenges during the initial research.

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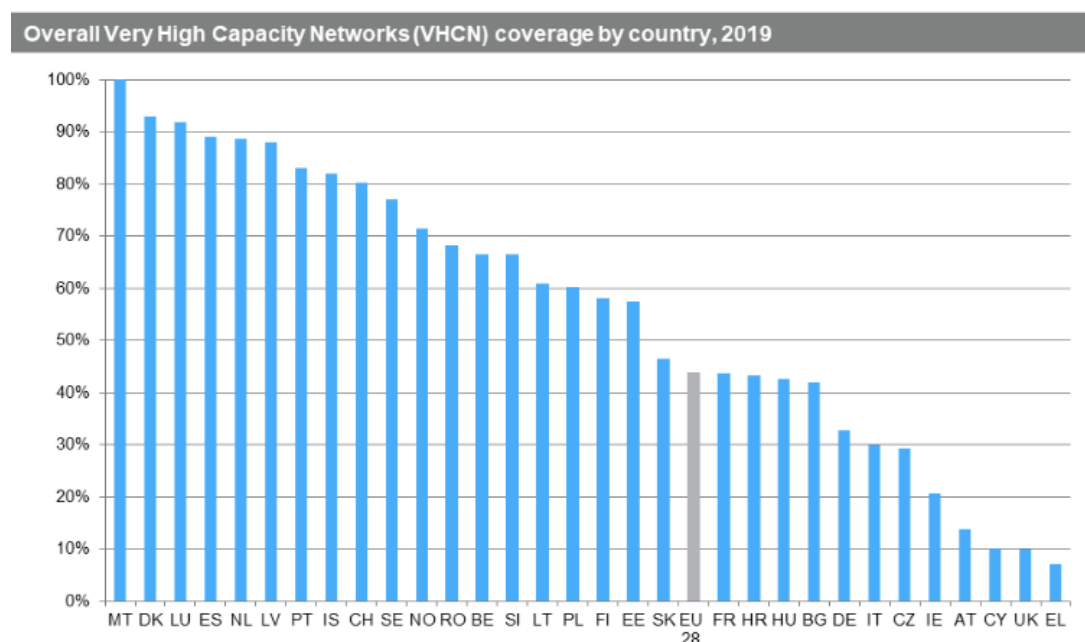
1 Introduction

The European Electronic Communications Code (EECC)⁴, adopted by the EU in December 2018, places an obligation on National Regulatory Authorities (NRAs) to promote investment in Very High Capacity Networks (VHCNs): defined as networks having performance parameters which are equivalent to those of a fibre-optic network at least up to the distribution point at the serving location⁵. Recital 23 states that NRAs should pursue “widespread access to and take-up of very high capacity networks for all citizens of the Union and Union businesses”.

This means that VHCNs should be able to deliver access speeds of 1Gbps and should therefore be based on fibre to the premises or using the cable DOCSIS 3.0 protocol.

The challenge of reaching this target is clearly illustrated in Figure 1, which shows a wide discrepancy between those countries with high levels of VHCN and the laggards. At the top end are Malta, Denmark and Luxembourg with coverage at over 90% of premises. At the lower end are Cyprus, the UK and Greece, which all had coverage below 10% in 2019.

Figure 1: VHCN coverage by country, 2019



(Source: European Commission 2019)

⁴ DIRECTIVE (EU) 2018/1972 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 establishing the European Electronic Communications Code

⁵ European Electronic Communications Code Recital 13

Four of the five largest then Member States in the EU in 2019⁶ had coverage in the lower half of all countries, taking the mean level of coverage below the median level by 16 percentage points (European Commission 2019). To increase the overall coverage of VHCNs will, therefore, require substantial levels of investment, which the European Commission recognises will have to come largely from the private sector, although some EU and national funds will be available.

As investment is largely in the hands of the private decisions of network operators and external investors, it is important to understand what determines where, when and how much these investors will make available to build VHCNs to meet the EU's ambitions.

Much has been written by researchers, regulators and consultants about drivers of investment in broadband and fibre. In general, these papers have concentrated on the relationship between investment and specific aspects of regulation and individual market dynamics. This paper contends that much may be missed by concentrating on single investment drivers when investment takes place in a complex system of multiple players with different ambitions and where there may be unforeseen and unintended consequences of investment or regulatory decisions. Further, much of the research on investment drivers does not take account of existing market structures and endowments, only taking a forward-looking perspective without examining any individual country's past.

This paper takes a different approach. It draws on System Dynamics to develop an holistic model of the various forces that determine investment in fibre optic and cable networks. By taking a whole system approach to modelling, the paper examines the interactions between various players and legacies to examine how they individually and collectively affect investment levels.

The paper is structured as follows:

- Section 2 briefly summarises the key literature on the drivers of investment in fibre and other next generation communications networks. It also provides a brief introduction to System Dynamics (SD) and reviews the SD literature related to electronic communications.
- Section 3 describes the SD model developed.
- Section 4 describes two country case studies based on the SD model to highlight how different countries have different determinants of investment in VHCN.

⁶ Since the report was published the UK has left the European Union.

- Section 5 concludes.

2 Literature Review

2.1 Drivers of Investment

There is a substantial literature on the drivers of investment in broadband networks and it is beyond the scope of this paper to review all relevant papers. However, three papers provide extensive reviews of the literature and so collectively point to the key drivers of investment.

Cambini and Jiang (2009) review a total of 57 theoretical and empirical papers that explore the impact of price and access regulations on investment. They conclude that the theoretical papers on price regulation show that the incentive to invest is related to the level of the price cap: the more the price cap drives down prices (and profits) the lower the incentives for investment.

With regard to access regulation, Cambini and Jiang find the theoretical papers are divided between those that argue mandatory unbundling negatively affects investment and those that take the opposing view, at least in some circumstances. The methodology used for cost-sharing, asset valuation and regulators' limited ability to make credible commitment *ex ante* need to be taken into account.

They conclude that the empirical findings exhibit a "certain disunity" (p. 571) and are of limited value due to the lack of sufficient data on which to draw unequivocal conclusions. Therefore, more empirical and theoretical work is needed before firm conclusions can be drawn.

Briglauer, Frübing and Vogelsang (2015) suggest that market forces alone will not trigger large-scale investment in NGA roll-out and so it is crucial to identify the right policy measures. They say that the "most controversial questions" are whether Next Generation Access (NGA) infrastructure should be subject to access regulations or a softer, deregulatory approach. Like Cambini and Jiang, they then consider both theoretical and empirical papers. They conclude that the theoretical papers suggest that softer, less onerous access regulation imposed on dominant undertakings will induce more NGA investment and improve social welfare compared with harder, cost-based access regulation. This theoretical finding is supported by the empirical literature, which points to a negative impact of *ex ante* regulations on dynamic efficiency.

The consultancy firm, WIK, undertook a study in 2015 for the UK's regulator of electronic communications, Ofcom, into the drivers of investment in superfast broadband (WIK 2015). In contrast to Briglauer, Frübing and Vogelsang, WIK found that regulation appeared to have less effect

on NGA coverage and take-up than market factors. They found no evidence that either regulatory forbearance or structural separation of the dominant network operator provided better outcomes for consumers in the short term.

WIK's study, based on an empirical analysis of twelve countries of which seven were in Europe, found that competition from cable networks and independent FTTP⁷ investors was the main factor which led incumbent fixed line operators to invest in NGA. They found a strong correlation between the coverage of cable using the DOCSIS 3.0 standard and the coverage of all versions of NGA and that investment by independent fibre investors was a strong stimulus for incumbent operators to invest directly in FTTP themselves. Cost of network deployment, using the percentage of the population in urban areas as a proxy, also had an effect on NGA investment, with more urbanised countries having higher levels of NGA coverage.

On the demand side, WIK found a significant pull from the availability of on-line video. End-users of broadband access required a higher speed line to watch streamed video at an acceptable quality. This trend has likely increased since the WIK report was written, especially as lockdown has led to an increase in the consumption of streamed video.

The most recent literature survey (Abrardi and Cambini 2019) focuses on studies that evaluate the impact of ultrafast broadband investment on different economic dimensions, but also examines the impact of different regulatory interventions on broadband deployment. Their overall conclusion is that it is hard to establish a clear relationship between regulation and investment due to a lack of variation in regulatory intensity at country level. There is also a methodological problem of endogeneity: essentially the difficulty of identifying cause and effect. Like Cambini and Jiang (2009), Abrardi and Cambini suggest more work is needed.

2.2 Introduction to System Dynamics

System Dynamics was developed in the 1950s by Jay Forrester, initially an extension of control theory to business problems, and was formally presented as a methodology in his book *Industrial Dynamics* (Forrester 1961)⁸. The SD paradigm recognises that a linear view linking goals and situations to problems, decisions, actions and results is likely to miss, *inter alia*, feedback loops between decisions and the environment and may also miss how the players in the system respond

⁷ Fibre to the Premises. This paper does not distinguish between fibre to the home and fibre to the premises. We have standardised on FTTP.

⁸ For introductions to systems thinking and System Dynamics, see Meadows 2008 and Warren 2002

to actions by each other. SD does not assume a mechanistic connection between a decision and outcome.

A system is described as a “set of elements that is coherently organised and interconnected in a pattern or structure that produces a characteristic set of behaviours, often classified as its function or purpose” (Meadows 2008, p. 188). The function or purpose⁹ of a system may be manifold. A sports team is a system (consisting of players, coaches, ground staff, supporters and so forth) with the purpose of winning; a charity is a system with the purpose of supporting a vulnerable group or asset; and a firm is a system with the purpose of creating a return for shareholders (amongst other potential purposes). A market can also be regarded as a system with a function of providing consumers with a good or service or perhaps meeting some other goal.

Systems can nest within systems. Thus, within a market system could be producers and finance companies who have different purposes to the function of the market overall.

A system is considered in SD to have two features: stocks and flows, and feedback loops that may be either reinforcing or balancing. These concepts are introduced below.

A stock consists of those elements of the system that one can see, feel, count or measure at any given time (Meadows 2008, p. 17). For a firm, that may be tangible and intangible assets. In electronic communications the number of properties connected to a network is a stock. Any stock is subject to flows, inwards and outwards. Thus, as more properties are attached to, or disconnected from, a network the stock increases or decreases. This may be considered as a flow of properties inwards and outwards. A net increase in the number of properties being added to the network means the stock will increase and will decrease if more properties leave the network than are connected.

This physical stock and flow may have a parallel financial stock and flow. A firm may have a stock of money to be spent on extending its network. That stock may be added to from external debt or equity investors and/or retained profit. The stock of money may be depleted as the firm spends money on building out their network and connecting more properties. In turn, once those properties become customers, they may generate profits that add to the stock of cash held by the firm.

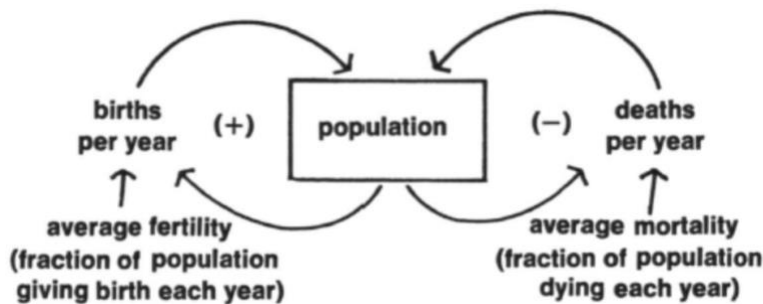
⁹ Meadows (2008) draws a distinction between “function” and “purpose”. A non-human system, e.g. a thermostat furnace, is said to have a function, whereas a human system has a purpose. The distinction is not absolute as many systems have both human and non-human elements.

This leads to the second important element of SD: feedback, or causal, loops. These are defined as “a closed chain of causal connections from a stock, through a set of decisions or rules or physical laws or actions that are dependent on the level of stock, and back again through a flow to change the stock” (Meadows 2008, p. 189).

We can think of a population of people in a country as a stock and the birth and death rates as the flows in and out. If there were no deaths, then the population will increase, in turn leading to more babies being born and the population increasing still further *ad infinitum*. This type of loop is known as a “reinforcing loop”, usually indicated by “R” in a casual loop diagram (CLD), or SD map.

However, any population also experiences deaths that counter the birth rate and keep some form of check on population growth. Deaths balance the birth rate and are shown in a CLD as a “balancing loop”, indicated by the letter “B”. These two loops are shown in Figure 2 below.

Figure 2: Birth and death causal loop diagram



Source: SERC.carlton.edu

If we consider an electronic communications network, the extension of the network would be reinforced by positive cashflow from earnings providing more investment capital, but ultimately balanced as the market becomes saturated and there are no more properties to connect.

One final point to make about systems is that it is highly unlikely that any one player controls the system. The actions of governments, customers, investors and competitors (to name a few) affect other participants and each of these stakeholders will take actions in response to those taken by others. This can lead to highly complex SD maps as we try to connect all the moving parts of a system, as will be seen later in this paper.

2.3 System Dynamics in Telecoms

This section of the paper reviews the literature on System Dynamics (SD) models in the telecommunications sector. Even though these are not necessarily related to investment determinants, these papers show how SD has been used by researchers in the telecommunications sector. The focus of this review is therefore on the potential for SD as a methodology rather than on what previous researchers have found about the determinants of investment using SD.

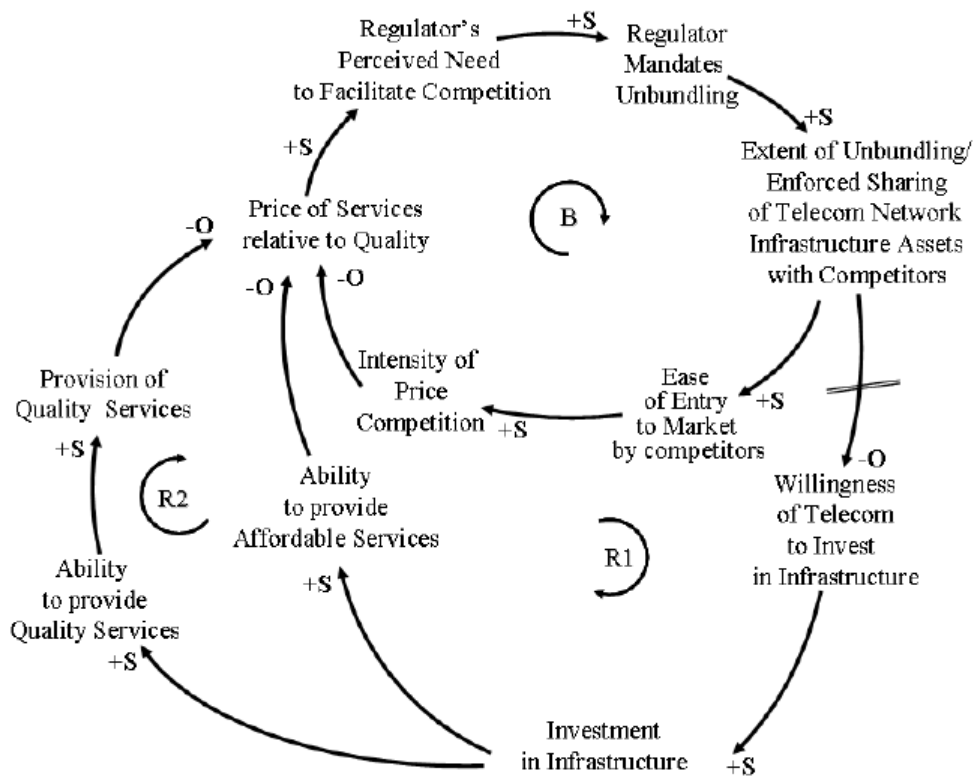
Davies, Howell and Mabin (DHM) (2008) compares two systems-views modelling techniques applied to the decision to unbundle local loops in New Zealand: SD and Theory of Constraints (TOC). SD is based on Causal Loop Diagrams (CLDs) that map the relationship between actions and outcomes and incorporates reinforcing and balancing loops – feedback mechanisms that either create vicious/virtuous circles or set some limit on an outcome – as discussed above. This is illustrated below as Figure 3 taken from DHM.

In their annotation an arrow marked +S has a positive relationship between actions at the tail of the arrow and outcomes at the head. Thus, we can see on the right hand side of the figure that the greater (lesser) the willingness to invest in infrastructure the greater (lesser) will be the actual investment and the greater (lesser) the ability to provide affordable services. By contrast an arrow with -O at the head depicts a negative relationship between an action at the tail and an outcome at the head. Again, on the right hand side, this depicts that the wider (narrower) the extent of unbundling and network sharing, the lesser (greater) will be the willingness to invest in telecoms infrastructure.

DHM describe the reinforcing loop R1 as follows starting from the left hand side:

“As the price of services relative to quality increases, the regulator's perceived need to facilitate price competition grows stronger, driving up the regulator's desire to mandate unbundling, increasing the extent of unbundling that takes place, impacting adversely on the willingness of Telecom to invest in infrastructure, leading to decreased investment in infrastructure, undermining the ability to provide affordable services, and then closing the loop, further increasing the price of services relative to quality.”

Figure 3: Illustrative CLD for the telecom unbundling case



Davies, Howell & Mabin (2008)

The balancing loop (B) shows that as the price of service increases relative to quality this increases the regulator's perceived need to facilitate competition through unbundling which eases entry to market competitors, increasing the intensity of price competition, which in turn decreases the price of service relative to quality, decreasing the regulator's perceived need to facilitate competition and so forth.

DHM provides a good example of how SD can be applied in electronic communications markets and contrasts SD with the TOC model, which seeks to resolve choice dilemmas by linking it to the overall systems goal. In the TOC model the authors frame the dilemma as whether or not to mandate unbundling, given the overall goal or objective of improving the price of services relative to quality.

The authors conclude that CLDs are better at communicating the interconnectedness and interdependence in a situation than the TOC narrative. This conclusion is quoted in full below.

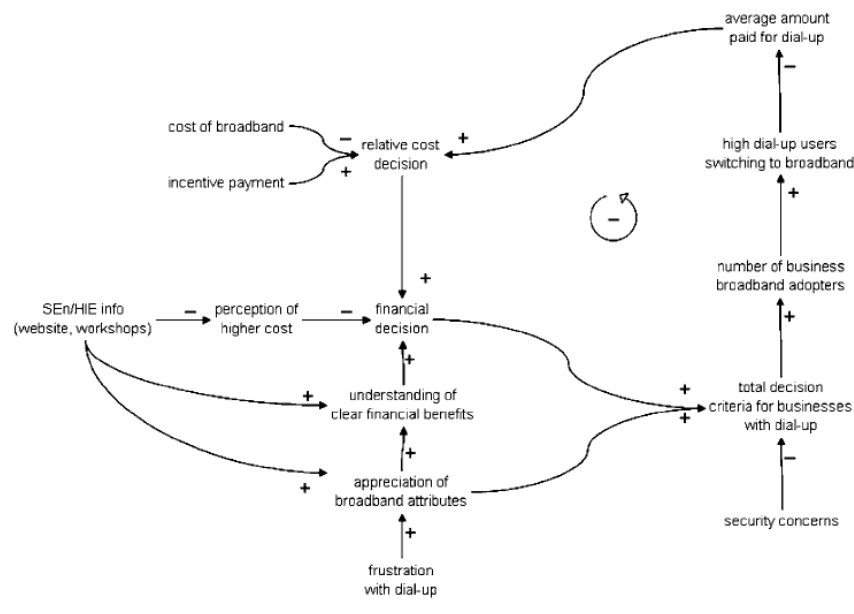
"In doing so, they can help build an understanding of the systemic nature of relationships, not only highlighting the dynamic time-based nature of feedback, the existence of balancing (B) and reinforcing (R) feedback loops, delays and side-effects; but also distinguishing

between individual (say, Regulator or Telecom) and systems behavior, between seemingly predictable individual behavior and local outcomes, and the systems behavior that may be expressed as the unpredictable or unanticipated 'emergent' properties of the system. (...) Additionally, we may gain recognition of how such individual or system behavior can lead to unintended, unanticipated, unwanted, yet often patterned and predictable outcomes or consequences – and therefore, how alternative actions may be more appropriately evaluated. (p. 161)

Two papers apply SD to help understand and shape policy decisions. In the first, Howick and Whalley (2007) use an SD approach to understand the drivers of broadband adoption in rural and remote areas of Scotland. At the time the article was written, 51% of Scottish households had Internet access, but only 30.6% of households had broadband access. The dial-up users were disproportionately in remote and rural areas of the country.

Howick and Whalley use CLDs to map the key factors affecting decision criteria for broadband adoption by current residential and business users of dial-up Internet access. Figure 4 below shows the key factors they identify as affecting the decision by businesses to adopt broadband.

Figure 4: Key factors affecting decision criteria for businesses with dial up



(Howick and Whalley 2007)

The authors say that the decision is primarily based on the costs and benefits of broadband relative to dial-up. However, factors such as the availability of an incentive payment and concerns about security may also have an effect on the decision.

Later in the paper, the portion of the SD model that captures influences on business is also presented followed by presentation of some results from the model. In particular, they present adoption curves for businesses and households assuming no future policy changes, which shows business adoption rate is slower than for households and that both segments reach saturation at about 80% penetration. They then simulate changing some of the policies to see which ones have the most effect on the penetration rate.

They first show the result from changing the impact of policies to encourage an appreciation of broadband attributes, shown on the left-hand side in Figure 4. This increased the rate of adoption but not the upper limit. The model identified a need to increase the number of households and businesses that believe that they do need broadband access, which in turn requires understanding the needs of people who currently believe that they do not need broadband.

The second paper (Casey and Töyli 2012) uses an SD model to examine the impact of technology harmonisation and mobile number portability (MNP) on the diffusion of mobile phones in Finland. They develop separate conceptual models of mobile diffusion and competition. The former describes how potential users interact with current users through a word of mouth process, and then how active users interact with mobile network operators (MNOs) who expand their network to meet expected demand. The competition model shows how firms interact with each other and how end-users respond to this. This model consists of three reinforcing loops that drive a decrease in mobile prices and three balancing loops that restrict any price decrease.

The authors construct a quantitative model using data from Finland, where, they say, the rapid diffusion of mobile can be accounted for by harmonised expansion of the GSM standard and that the Finnish regulator (FICORA) promoted competition, with MNP as a key policy. They use this quantitative model to undertake retrospective simulations of the diffusion and usage of second generation (2G) mobile networks testing the effects of technology harmonisation and MNP.

They find that a policy of technology harmonisation rather than competition had a positive effect on diffusion, with the user base reaching near full penetration earlier under harmonisation than if the regulator enforced technology competition. The 'Direct network effect' reinforcing loop identified in the conceptual model was stronger under harmonisation, in part reflecting more affordable handsets. Users also enjoyed the network effect of being part of a worldwide base of interoperable handsets and networks.

With regard to MNP, they found that its introduction lowered entry barriers leading to a rapid increase in the number of MNOs and a stronger 'increasing demand' reinforcing loop. However,

increased competition led to diminished profitability and to firms exiting the market or merging. When MNP is not introduced in the simulation, the number of MNOs remains limited.

The final paper reviewed here is Graham and Godfrey (2005), which presents a case study of the use of SD modelling in a regulatory dispute in Hong Kong. They explain the background to the case as the Hong Kong telecoms regulator (Office of the Telecommunications Authority – OFTA) wanting to increase competition by issuing a fifth 3G competitor to use the CDMA technology. Hutchison Telecom HK was particularly concerned about this proposal as it meant that it would be required to hand back some of its 2G spectrum for the new operator.

Hutchison worked with PA Consulting Group to develop a System Dynamics model of the Hong Kong market that could be used to calibrate the effect of the additional licensee. They developed a number of Causal Loop Diagrams (CLDs) showing the interrelationship between different players and actions in the market in an attempt to capture an understanding of the market system.

Two particularly interesting, and relevant, insights from Graham and Godfrey are quoted below:

“An interlocking and complex set of markets lies between regulatory action and the downstream consequences for the public, and it is easy for different stakeholders to draw different conclusions.” (p. 3)

and

“The insensitivity of the regulatory impact to many assumptions will not be a surprise to System Dynamics modellers. The behavioural characteristics of feedback systems are often surprisingly insensitive to most parameter changes.” (p. 9)

This suggests that other forms of modelling may overstate the effect of specific variables, whereas SD shows how other variables may respond to such a change or absorb the changed variable in the overall system.

Overall, we conclude three key lessons from the literature on SD and telecoms. First, SD can be used effectively to identify and map the decisions between various stakeholders in the market and their outcomes, including feedback loops that reinforce or balance those outcomes. These go beyond simpler linear models that suggest a direct cause and effect. Secondly, SD can be used to map the complex interrelationships between stakeholders and the many paths that outcomes from decisions can flow through the system. Finally, SD points to a need to place any policy action in the context of the system rather than making an assumption that the same action will have the same outcome regardless of the system it exists within.

The ability of SD modelling to map complex interrelationships within a system and establish how actions in one part of the system affect the whole system makes it particularly valuable when seeking to establish the likely consequences of decisions made by participants in the system. As will be shown in the next Section of this paper, the VHCN system is highly complex with a great number of players with different individual objectives. Within the overall VHCN system, with its function of delivering gigabit capacity connections to consumers, are the many other systems of stakeholders (incumbents, entrants, investors and so forth) each of whom may have different purposes and will react to others' actions in their own interests.

3 A System Dynamics Model of Determinants of Investment in Very High Capacity Networks

3.1 Introduction

Development of the SD model followed a three-stage methodology. In the first stage a comprehensive list of the drivers of investment was developed. This was based on extensive secondary research of over 100 publications by consultants, regulators and academic researchers together with interviews with regulators, network operators and investors. Stage two was the development of a Generic Network Business Model (GNBM) linking the drivers of investment and identifying both reinforcing and balancing causal loops. This GNBM was deliberately not specific of a single country or network operator type¹⁰ but aimed to capture the complete system for all of Europe. Finally, stage three examined how the GNBM could be applied to individual country examples to establish the determinants of investment in the country and how they might differ from other countries. Each of the three stages is reported below.

3.2 Stage 1: Identifying Drivers of Investment

Given that most investment in VHCNs in Europe will be made by private sector players, it is necessary to identify on what motivates private investors if we are to establish the determinants of investment

Our research confirmed that the expected Net Present Value (NPV) of a potential investment was the key decision-making tool for potential investors. As one interviewee, an external investor, explained: "If the NPV is large enough we'll invest, if not we won't". This reflects the finding of Charles River Associates (2012): "Investment will take place when [investors] believe that the NPV is high enough; not when regulators deem it so".

¹⁰ Such as cable, incumbent or entrant.

The well-known NPV equation (below) establishes the return on an investment given three key variables: the initial level of capital investment (K), the net cashflow arising from the investment (π) and the cost of capital (r) over a period of time (T).

$$NPV = -K + \sum_{i=1}^T \frac{\pi}{(1+r)^i}$$

The first stage in establishing the determinants of investment in VHCN is therefore to establish a “long list” of those conditions of the market that affect the how much capital needs to be invested, the likely cash flows and the cost of capital. These are discussed below. Individual organisations in the sector may identify additional factors that influence investment, but the set listed below are those where there was some degree of consensus amongst interviewees and secondary sources reviewed.

Capital Costs

Capital costs capture the capital expenditure (CAPEX) of undertaking all activities involved in deploying VHCN infrastructure. This capital expenditure:

- Increases the number of premises passed by the operator’s network and/or connects premises to the network – typically this will involve FTTP deployment¹¹; or
- Increases the capability of an existing network connected to premises – typically this will be measures to increase the speed of a copper network, such as FTTC, or increasing the capability of an existing cable network by upgrading to DOCSIS3.0 or 3.1.

The level of capital expenditure needed is affected by various conditions, set out in Table 1.

Table 1: Conditions affecting capital costs of network build

Effect of capex	Description
Population density	More populous areas with a higher density of residential and business premises require lower levels of capex to reach a similar number of premises than rural, low density population areas (BEREC 2016, WIK Consult 2015 and FTTP Council Europe 2017).

¹¹ This is an example of stock and flow. The investor provides a stock of financial capital to the firm which creates a stock of network assets using the flow of capital expenditure. The faster the capital expenditure the faster the flow of properties from not connected to connected.

Wayleaves and administration costs:	<p>Planning and administration accounts for around 15% of the cost of network build¹². Some of the elements of this cost are:</p> <ul style="list-style-type: none"> • Noticing and permit schemes. • Restriction notices that prevent street works within a time period of the previous works. • Road traffic management. • Planning permission. (Analysys Mason, 2017) <p>Local property taxes may be added to this list if they apply to fibre networks.</p>
Duct and pole access	<p>Building a broadband network from scratch is largely a civil engineering project. An investor needs to dig trenches to lay cables, usually in a duct of some description. In some areas it may need to erect poles from which to hang cables. Estimates vary about the proportion of the cost of network build accounted for by civil infrastructure, but a commonly used estimate is around 60% - 80%.</p> <p>The re-use of existing physical infrastructure has the potential significantly to reduce the capital investment cost per premises passed (Prism Business Consulting & Tactis, 2017). However, this requires sufficient physical infrastructure to be available, in good condition and, normally, a regulatory obligation on the infrastructure owner to provide access to other network developers. Not all countries have a significant duct network that can be reused by other operators. In some countries a large proportion of cables are directly buried in the ground or not useful for some other reason, such as having collapsed. Where ducts are not in sufficiently good condition to be reused, they do not reduce the cost of network build.</p> <p>The EU sees access to existing physical infrastructure as an important driver of investment. The Broadband Cost Reduction Directive¹³ (BCRD) aims to make both telecoms and non-telecoms infrastructure available to companies laying fibre networks.</p>
Civil engineering costs	<p>The costs of building a network can also be reduced through methods such as co-investment (where several operators contribute to the cost of the network), new trenching techniques (such as micro-trenching) and voluntary labour (usually only appropriate for rural community broadband</p>

¹² Interviewee response. Unable to confirm figure from published documents.

¹³ DIRECTIVE 2014/61/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on measures to reduce the cost of deploying high-speed electronic communications networks

	schemes). Co-investment is regarded as an important driver of investment by the EU and is specifically mentioned as such the EECC ¹⁴ .
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Net Cashflow

Net cashflow refers to the EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) from operating the VHCN. Sufficient EBITDA is required over the period of the NPV calculation to exceed the capital costs with increasing discounting of the value of future EBITDA. The three primary influences on net cashflow are set out in Table 2 below.

Table 2: Conditions affecting net cashflow

Effect on cashflow	Description
Demand	<p>Clearly the level of demand is crucial and demand has a number of drivers. Drivers of demand can be underlying global factors such as development of technology, and endogenous drivers where local conditions might encourage demand. Some of these underlying and endogenous drivers of demand are:</p> <ul style="list-style-type: none"> • Consumer income • Consumer entertainment • Level of homeworking • Connected devices per household/business premises • Access to government services • Copper switch-off <p>Public policy may also be used to drive demand. Policies that have been observed in the market have been grouped into four criteria:</p> <ul style="list-style-type: none"> • Policies intended to promote the use of devices; • Policies that promote the development of services and applications; • Policies that promote digital literacy and skills; and

¹⁴ See EECC Recitals 198 – 201 and Article 76.

	<ul style="list-style-type: none"> • Policies that reduce the cost of broadband connections. (Bourreau, Feasey & Hoernig, 2017)
Alternative access technologies	<p>Demand for VHCN access will also depend on alternatives available. If copper networks can only deliver low bandwidths (due to long lines), demand for VHCN can be expected to be higher compared to cases where the copper network has been upgraded to FTTC with relatively short lengths of the remaining copper sub-loops. The relative utility of these alternative technologies will affect the revenue operators of VHCN can extract from the market.</p>
Operating expenditure (opex)	<p>The level of opex has a direct effect on net cashflows as higher opex obviously reduces net revenues, assuming revenues remain constant. Amongst the operating costs that must be covered by revenues are:</p> <ul style="list-style-type: none"> • Leasing costs • Energy costs • Maintenance costs and • Management and customer services costs. <p>Where the incumbent can completely replace its copper network with fibre it can reduce its opex as fibre networks have lower operating costs. Lower operating costs improve cash flow <i>ceteris paribus</i>.</p>

A fourth driver of cashflow is competition, although this can both increase or decrease net income. Competition can increase cashflow in a growing market if it stimulates demand, through means other than lower price, such that more consumers are prepared to purchase VHCN access. However, competition can reduce net cash flow in a mature market if it erodes the earnings available to firms and drives prices towards cost.

Cost of Capital

The final element of the NPV equation is the cost of capital required for any investment in VHCN. The expected return and the time horizon for payback will depend on the nature of the investment, type of operator and the expectations of investors. The conditions affecting cost of capital are set out in Table 3 below.

Table 3: Conditions affecting cost of capital

Effect of cost of capital	Description
Expectation of investors	Investors have different expectations. Investors in infrastructure assets, such as VHCN, are generally looking for a long term investment with a steady, secure cashflow, rather than a high return on a short term investment (Della Croce 2012).
Confidence in revenue generation	<p>Where there is greater confidence in the revenue generating possibility of the investment, investors may be willing to accept a lower return on the investment as risks are lower. Conditions that may increase confidence include:</p> <ul style="list-style-type: none"> • Demand aggregation • Anchor tenants • Low risk of overbuild by competitors • Regulatory certainty • Level of regulated Weighted Average Cost of Capital (WACC). (Bourreau, Feasey & Hoernig, 2017)
Co-investment	In addition to reducing capital costs, co-investment is expected to reduce the level of risk for any individual operator and so potentially reduce its cost of capital.
State Aid	State Aid is available for some areas in EU rules. Where such capital is available, again the cost of capital may be reduced.

3.3 Generic Network Business Model

This section describes the development of a generic representation of a network operator business system using the System Dynamics approach, describing it visually through links of cause and effect. The network operator’s business system has been chosen as it is these companies that are the major investor in VHCN, even when investing externally sourced capital. The resulting map has been used

as the starting point for qualitative analysis of markets and operators and thus establishing the determinants of investment¹⁵.

The aim of producing a Generic Network Business Model (GNBM) is to capture, within a single visual representation, a model that can be applied to any national market, region or operator. It, therefore, needs to represent completely the variety of operator business systems observed across Europe. This variety of operators includes financiers, regulators, consumers and retailers.

The GNBM must reflect:

- Drivers of investment discovered through the interviews, literature reviews and analysis.
- Wide variety of operator business models (at different stages of maturity across EU markets). These include former incumbent operators, cable companies and new entrants, including those that offer a “wholesale only” proposition.
- VHCN infrastructure as part of technology evolution that cannot be separated from existing Copper and Hybrid Fibre Coax (HFC) cable-based network operations.
- Existence of geographical market segmentation, where appropriate.
- Endogenous nature of competition – the network model must reflect the influence of other operators within the market.

The resulting model is complex in its attempt to capture the variety of markets across the EU. However, it can be simplified for application to a specific market, region or operator where not all the components are relevant (often due to path dependence), and this approach has been applied for country analyses that will follow.

Before describing this model, it is important to emphasise that the model is qualitative but provides a toolset to think about and articulate what is observed in markets and to explain how operator behaviour may unfold.

As described earlier, one of the features of an SD model is the use of “stocks” and “flows”. At the core of the GNBM, shown in Figure 5 below are a number of boxes plotting the stock of premises at different stages of the system: from not being connected to a VHCN, to being passed but not

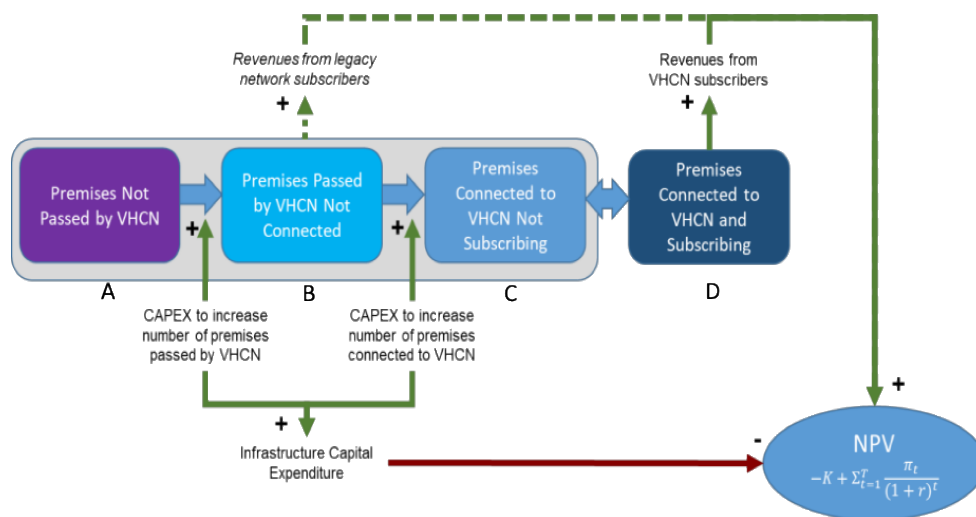
¹⁵ SD can be used to develop quantitative analysis, showing the extent to which parts of the system are affected by decisions made elsewhere in the system. This project, however, has been limited to a qualitative analysis.

connected, being connected and eventually subscribing to a VHCN. Around this core are a number of causal arrows that form the basis of an investment decision based on expected NPV. To move from Box A on the left, where premises are not passed by a VHCN to Box B and Box C, where premises are passed by not connected or subscribing, requires capital expenditure (K). The positive sign at the head of the arrow indicates that a higher capex is required to connect more premises. The negative sign above the arrow pointing to the NPV equation indicates that a greater capital expenditure has a negative effect on the NPV equation and so will require a higher level of income.

The arrow pointing upwards from Box D indicates revenues generated from customers of the VHCN feeding in a positive cash flow to the NPV equation, provided that demand for VHCN exists.

The greater the level of capital expenditure, the faster the flow of premises from left to right and so the greater the cash flow generated. The flow of premises from the “not passed” stock to the “connected” stock is largely a function of investment increasing supply of VHCN capable premises. The stock of “connected and subscribing” properties is a function of demand, which can determine the level of investment once known.

Figure 5: Core concepts of CAPEX and net revenues forming the basis of the NPV investment decision



The various drivers of investment were then plotted around this core model to create a generic, qualitative SD model capturing all the various factors that can influence the level of investment in VHCNs, although it is highly unlikely that all drivers will be found in any single market. The generic model (Figure 6) is complex due to the complexity of the system but has been divided into a number of areas described below.

- VHCN provision – this sector represents premises within the market and the infrastructure implementation activity to bring VHCN capability.
- VHCN subscriber uptake – this represents VHCN new connections and development of an active VHCN subscriber base.
- Legacy network provision – this represents implementation of investments on a legacy copper network, if the operator current possesses such an asset.
- Legacy network subscriber uptake – representing the acquisition and retention of subscribers on the legacy network.
- Network operator decisions and accounts – this provides a representation of the management accounts for the operator.
- Network financial investment – represents how and where network investment will be directed.
- Retailer operator decisions and accounts – Retailers are part of the business system using the network (e.g. via VULA) to compete for and acquire a subscriber base. The network operator with a vertically integrated operation will also be part of this competitive retailer market.
- Competing VHCN subscriber propositions – represents the competition between VHCNs, retailers on these networks and the legacy Copper based propositions.
- Consumer VHCN demand – this captures the fundamental demand for VHCN dependent services and consumers demand for 1Gbit low latency connections.

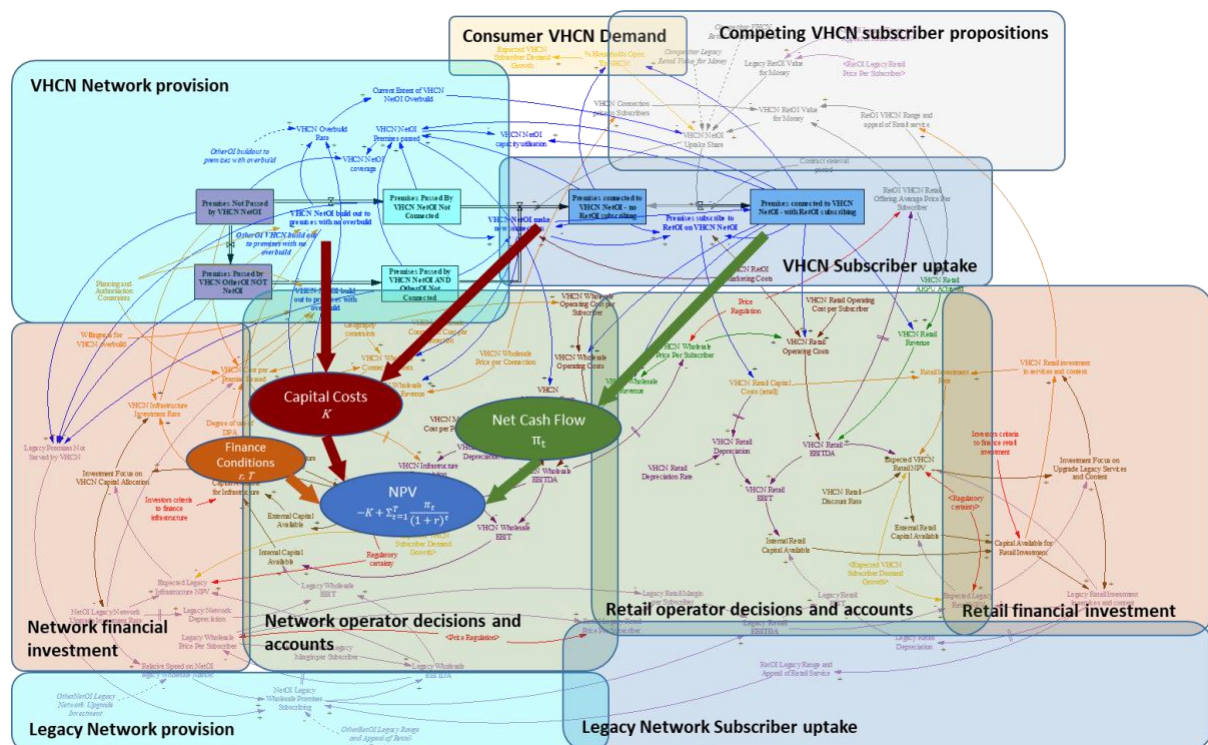
Whilst the high-level map captures all identified links and feedback loops, it is almost too complex to help understand the determinants of investment in any specific country, at least without significant time spent to review and understand the diagram. The next stage of research, therefore, is to apply the relevant parts of the generic map to specific country examples and from each country specific map to identify that country's determinants of investment. The following section reports two example countries, Ireland and Spain, that illustrate how the SD approach can be used to identify determinants of investment. Two other country case countries were examined: Sweden, where high demand and local municipality involvement were important determinants and the Netherlands

where very high cable coverage was important. These examples are include in the summary table (Figure 11 below) but not reported in detail here.

Figure 6 below shows the generic map with the elements of the NPV equation overlaid. Boxes A – D above appear in the centre of the model, with two further boxes below boxes A and B to represent competitive investment.

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Figure 6: High level sector map of the generic network operator model with NPV



3.4 Ireland: A Model of Competition

A review of the history of the development of VHCN in Ireland shows the importance of competition between cable and copper networks as a key determinant. In the period between 2010 and 2014 cable broadband was successfully challenging DSL and taking market share. In 2012 the cable network, operated by Virgin Media, passed about 50% of premises in Ireland and 42% of homes passed could be connected using the DOCSIS 3.0 protocol¹⁶.

By contrast, the copper network was largely ADSL with almost no FTTC and no FTTP. The result was that cable companies were eroding Eir's¹⁷ broadband market share as Eir was unable to provide the utility provided by cable. Table 4 shows that DSL subscriptions had remained more or less constant between 2010 and 2012, declining slightly from 734,000 to 727,000. By contrast, cable subscriptions had increased by around 50% from 203,000 to 306,000 over the same period.

Table 4: Ireland Broadband Subscriptions (x1,000) by Platform

	2010	2012	2014	2016	2018	2020
FTTP				9	90	224
VDSL (FTTC)			202	499	619	645
DSL	734	727	630	436	296	202
Cable	203	306	367	366	373	374
Other	83	77	60	51	54	59
Total	1,020	1,110	1,259	1,360	1,430	1,504

Source: Comreg Quarterly Key Data Reports. All data for Q4 in each year, except 2020 where data is for Q3. Subscriber numbers for 2016 and 2018 are calculated from data shown in the reports.

Eir responded to the competition from cable by upgrading its copper network to FTTC, increasing VDSL coverage from 0.5% of premises in 2012 to 61% in 2014 and reaching 86% in June 2017, when most of the network with sufficiently short copper lengths had been upgraded. It initially targeted urban areas where it faced the toughest competition from cable and then continued to expand beyond the cable footprint and into more rural areas, albeit at a slower rate. The effect was that Eir was able to counter the competitive threat from cable and there was almost no growth in cable subscribers between 2014 and 2020.

Eir's network reportedly had few re-usable ducts, so it would not have been possible to employ FTTP nearly as quickly and the costs would have been substantially (and likely prohibitively) higher¹⁸.

¹⁶ Source IHS and Point Topic - Broadband Coverage

¹⁷ The incumbent fixed line operator in Ireland.

¹⁸ Information supplied by well positioned interviewee. No other source found to verify.

From an NPV perspective, the investment in VDSL would have been a rational business decision in response to the loss of market share and the costs and timescale of meeting that competition.

Investment in FTTP began in 2016 and by 2020 some 225,000 households and businesses could subscribe to an FTTP service. Virgin Media responded to Eir's investment in FTTP by upgrading nearly all its network to DOCSIS 3.0. In August 2020 it claimed to be "the country's largest Gigabit broadband provider" able to offer 1 Gbps broadband to 97.5% of premises across the Virgin Media network (Virgin Media 2020).

The high-level SD model for Ireland is shown in Figure 7. This shows the basic NPV decisions for fibre with deployment costs and demand drivers, with the addition of a representation for the copper network. The copper network investment representation can be thought of as a very simplified representation of an investment structure similar to that of FTTP.

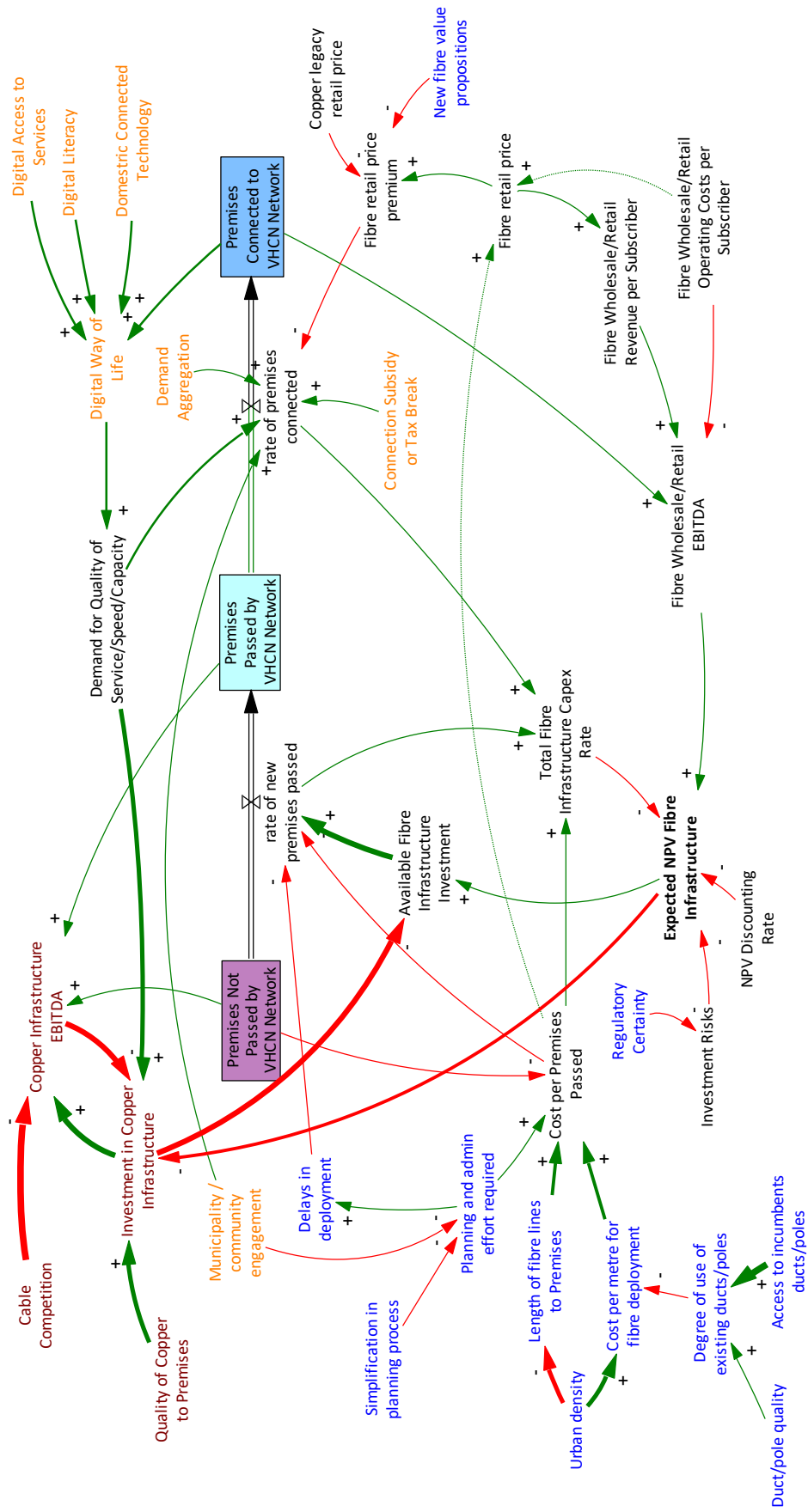
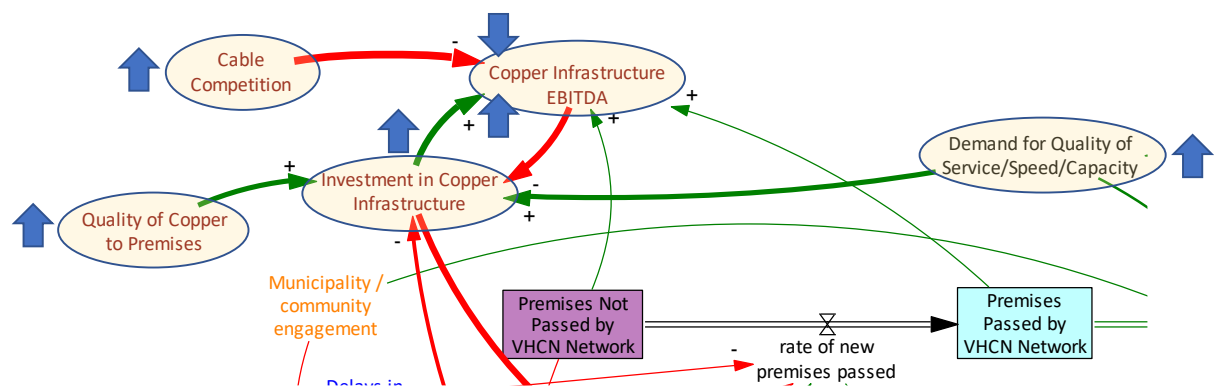


Figure 7: High-level narrative model for Ireland

Key aspects of the copper upgrade decision mechanism are highlighted in Figure 8, which is an extract from the top left-hand corner of Figure 7. Cable competition was eroding the legacy copper network’s market share putting pressure on the profitability of the network. Market share for ADSL can be seen in Table 4 with a steady and significant fall between 2009 and 2012. The presence of high-quality copper, at least in urban areas, provided the opportunity to upgrade the existing copper network for FTTC/VDSL to improve capability sufficiently to halt and reverse the loss of subscribers to cable, and thus the profitability of copper. Investment in upgrading the copper network will tend to slow as the pressure of profits are reduced but continued at a slower pace in Ireland after 2014 until most of the network that could be upgraded had been.

Figure 8: Excerpt of Ireland high-level narrative highlighting the copper upgrade decision drivers



Cable Competition erodes Copper Infrastructure EBITDA by reducing market share and revenue. Loss of Copper Infrastructure EBITDA encourages an increase in investment in VDSL/FTTC Copper Infrastructure (a negative influence as shown by the red line means a change in the opposite direction). Investment in a better performing Copper Infrastructure means it is better able to stave off competition from Cable and so helps to protect EBITDA. Investment in Copper Infrastructure is only effective if there are good quality, short connections from cabinets to premises. Investment in VDSL/FTTC is only effective if there really is demand for QoS/Speed/Capacity so that customers will switch DSL subscriptions to a higher price VDSL subscription.

3.5 Spain: Supply Side Led Development

Spain has the fourth highest coverage of VHCN in the EU and is the only one of the four largest EU Member States to have above average coverage (see Figure 1 above). VHCN coverage in 2019 was 89%, double the EU average of 44% (European Commission 2019).

In contrast to Ireland, rather than being driven by competition, investment in Spain was strongly influenced by the availability of high quality ducts with spare capacity, regulatory actions that explicitly targeted investment in VHCN and encouraged investment in fibre by Telefonica's competitors (Medina 2017, NERA 2018). Spain's road to a high level of VHCN coverage can be described as supply-side led.

The high-level narrative model for urban areas in Spain is shown in Figure 9. In urban areas the NPV business case for investment has benefited greatly from a low cost per premises passed due to the ability of infrastructure operators to make use of existing ducts all the way to the premises. Regulation and effective enforcement provided access to duct infrastructure for any operators that wanted to deploy their own infrastructure. Compared with the requirement to dig new trenches for ducts, this can save around 60% of deployment costs. Urban density and high proportion of multiple dwelling units in many Spanish cities also reduced costs for deployment of fibre. These impacts are highlighted in Figure 10.

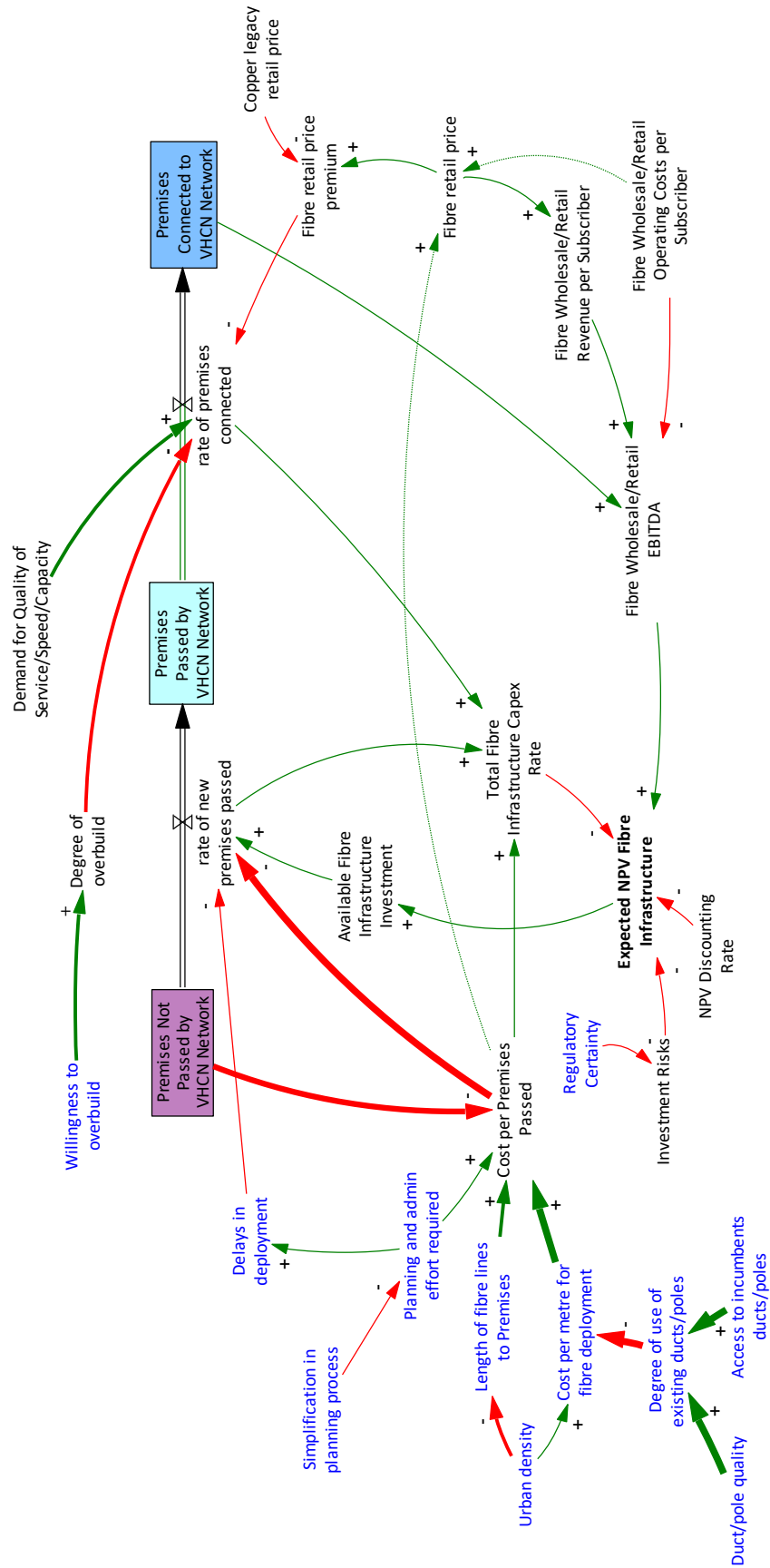


Figure 9: High-level narrative model for Spain (urban areas)

tenants by being able to offer considerably superior speeds via FTTP infrastructure. At the same time, competitors could respond to the threat by deploying their own FTTP infrastructure using the wholesale duct offer, so creating the conditions for infrastructure competition. Afterwards, from 2016 onwards, Telefónica had to provide FTTP wholesale access in non-competitive areas for ultrafast broadband services, but Telefónica enjoyed price flexibility, ensuring competition while also fostering investment.

- ii. Cable, with close to 50% coverage, provided an existing form of infrastructure competition with investment in the cable system to upgrade to DOCSIS3.0 in 2011/12 enabling higher speeds than copper. Despite this, cable broadband suffered continuing loss of market share from 22% in 2011 to just 15% in 2019 and reached a peak number of subscribers in 2016¹⁹. Although competition was weak from the perspective of market share, the investment in DOCSIS 3.0 was a key trigger for FTTP deployment (Feijóo et al 2015).

Low deployment costs for fibre, competition from cable and the speed restrictions on wholesale access created a high willingness to overbuild, providing infrastructure competition. This is highlighted at the top of the Spain narrative diagram.

The success of this regulatory approach of restricting wholesale access was dependent on Spain's relatively low installation costs for FTTP, resulting from good duct access and therefore relatively low capital requirements, compared with the majority of EU countries. It also required active enforcement of duct access obligations and symmetric building wiring obligations for the approach to be successful.

Demand-side drivers for VHCN in Spain have not been significantly strong, especially bearing in mind that revenues needed to support overbuild by multiple infrastructure operators. As with most EU countries, subscription rates for higher speed broadbands had been low in Spain in past years, with less than 2% of the population subscribing to VHCN (ultrafast) broadband in January 2014 and rising to 18% of households in June 2017 despite 84% of households having access to VHCN and 100 Mbit/s retail prices generally the same as copper prices. However, by June 2018 VHCN coverage was 87% of households and more attractive value propositions had helped subscription rates jump to 30% (DESI, 2019), as compared with an EU average of 20%.

¹⁹ Source: CNMC http://data.cnmc.es/datagraph/jsp/inf_anual.jsp Downloaded 7th May 2021. The number of cable subscribers peaked after the market share of cable due to the increasing market size.

The successful implementation of duct access regulations leading to low capital costs for infrastructure deployment meant that the NPV business cases could be made for FTTP investment despite the low subscription rates and with overbuild by multiple operators effectively dividing that subscriber-base between them. The success of these business cases is attested by the fact that they continued to attract investment capital.

3.6 Ireland and Spain: A Comparison

Figure 11 tabulates some of the key determinants of investment in Ireland and Spain and two other countries, Netherlands and Sweden, to illustrate the key differences between countries.

Figure 11: Summary of Determinants of Investment in Ireland and Spain

	Ireland	Netherlands	Spain	Sweden
Urban population	66.5%	92.8%	82%	90.7%
Availability of physical infrastructure access	Duct and pole access introduced as a remedy to Eir's SMP in the wholesale local access market in 2018.	No regulated access to physical infrastructure	Excellent in urban areas and available from 2008. Access to Telefonica's ducts introduced by law in 2008 and access to any utility's duct in 2016.	Regulated access to ducts and pipes as a remedy in the Wholesale Local access market
Competition	Eir had been losing market share to cable that was able to offer a better user experience than ADSL. Responded by introducing FTTC as a low cost way to increasing access speeds. Later investment in FTTP by Eir and DOCSIS 3.1 by Virgin Media	Cable broadband is almost ubiquitous in Netherlands. By 2019 approx. 95% of households had access to DOCSIS3.0 and 77% to DOCSIS3.1. By FTTP reached only 34%, and mostly in rural areas.	Weak competition from cable that was losing market share since early 2000s. Felt some need to respond to upgrade to DOCSIS 3.0 in 2011/12.	Sweden has a history of local authorities investing in local fibre networks, often on a wholesale only basis. 77% of households have access to FTTP.

	increased access to VHCN.			
Regulation	Not specifically targeted to encourage investment in FTTP until 2018.	The Dutch NRA (ACM) attempted to impose joint dominance on KPN and Vodafone Ziggo in wholesale local access market in 2018. Decision was rejected by the courts and so market is unregulated. ACM now found KPN solely dominant, but European Commission has notified objections in March 2021	NRA explicitly designed regulation to encourage Telefonica to invest in FTTP and to facilitate duct access for other operators to invest in own networks.	Swedish NRA (PTS) defined a national fibre market but this has been challenged by European Commission (March 2021)
Demand	No country had particularly strong demand. Linear growth rates for fixed broadband access			Demand led market with a strong digital way of life.

The analysis above shows that competition was a determinant of investment in fibre in all countries but was strongest in Ireland. However, the legacy conditions that existed countries affected the way in which operators and regulators responded.

In Ireland, Eir took the pragmatic route of rolling out FTTC where it could, i.e., where copper lines were relatively short in urban areas, to be able to offer a competitive product and so regain market share from cable. This was followed by both Eir, along with some smaller entrants, and Virgin Media investing in FTTP and DOCSIS 3.1 respectively to be able to offer gigabit access as widely as possible.

As of Q3 2020, some 225,000 households had subscribed to FTTP and 374,000 to cable. However, whilst FTTP is growing its numbers, cable penetration has been more or less static since 2014.

In Spain, the NRA took advantage of an excellent duct and pole network in urban areas to encourage both Telefonica and other operators to develop FTTP networks in the same ducts. There are some 18.7 million households in Spain and, according to data from CNMC, some 54 million FTTP lines. This means that on average each household has an average 2.8 networks it could choose from. Ten million households can also obtain broadband from a cable network.

4 Conclusions

The research reported in this paper collated a broad set of quantitative and qualitative data gathered through stakeholder engagement and publications and synthesised this within an holistic systems-based model of the electronic communications network business sector. The study has demonstrated how such a model can be used for cross market comparisons and understanding the determinants of investment choices made by network operators.

The study has revealed a wide range of drivers of investment, listed in Table 1 to Table 3 above. Each of these can be linked to the fundamental components on investment decision-making: capital expenditure, future cash flows arising and the terms of the investment.

Many of the drivers of investment within these broad categories have been previously identified in other studies. However, adopting the SD approach has demonstrated in a novel way how these drivers are interconnected and dependent on each country's legacy conditions. A simpler, linear model of determinants of investment would fail to describe the full system and so limit understanding of what determines the level of investment.

The SD model allows us to draw a number of key conclusions.

There is a difference between drivers of investment and determinants of investment - the breadth of enquiry identified a universal set of drivers, most of which are well known. However, the use of an SD model shows determinants of investment are path dependent, contextual and depend on the conditions within a country and will differ between operator business models. Not all drivers of investment will be relevant in all circumstances. For example, physical infrastructure access is not a determinant of investment where such access is not available.

There is no universal strategy that will work for all countries – It follows from the above that there is no universal strategy that will work for all countries. Policymakers and regulators must take

account of local circumstances and legacies. However, they can learn from other markets as they evolve if the lessons become relevant.

Conditions are not static – markets evolve, and the conditions change. For example, demand for VHCN evolves which impacts revenue potential; increasing capital build costs as premise coverage increases (as only the more expensive premises to reach remain); experience and technology development reduce capital cost and business case risk. The current Covid-19 pandemic that has accelerated the trend of home-working and the consumption of streamed media has changed demand for high capacity networks.

Competition does drive investment - Competition creates opportunity for disruptive entrants to invent profitable business models and this, coupled with cable's advantageous incremental upgrade strategies, can force a switch by the incumbent to react with its own investment or lose market share. How incumbent operators respond to competition from cable and other fibre-based entrants will depend on national circumstances and a universal response cannot be predicted. Across the markets reviewed, incumbents have demonstrated both reactive and proactive VHCN investment responses to such threats.

4.1 How whole systems modelling has created new insight and its limitations

The whole systems modelling has proven to be an innovative approach to understanding determinants of investment. Creating a **single** model and framework to compare markets, regions and network operators has provided a robust way to consider if insights from one market are relevant in others.

The modelling has demonstrated that markets at very different stages of VHCN penetration and path dependence can still share the same challenges within their VHCN ecosystems. This has been demonstrated for Spain and Portugal where very high coverage and penetration can still mask the challenge for rural areas with high VHCN build costs – a problem shared by most other countries.

The systems modelling approach has been a very different start point for considering VHCN investment determinants. This contrasts with much of the academic literature that uses the regulatory frameworks as the starting point for analysis and modelling. The systems approach has created a model where regulatory levers can have multiple touchpoints in the corporate investment decision making.

Another advantage of describing corporate business models is to reveal and describe the diversity of the network operators from the largest national operators through new entrant start-ups and municipalities and local communities.

The models described and the supporting analysis have been qualitative and this is aligned to the study requirements. Qualitative analysis does have a limitation in the degree of validity that can be attached and also in generating forward looking estimates for the industry standard metrics to measure VHCN investment and take up. The qualitative approach is valuable at the very earliest stages of NRAs undertaking market reviews and considering candidate regulatory actions. However, as per Howick and Whalley (2007) SD models can be used for quantitative analysis.

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