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Feeding a Need for Speed or Funding a Fibre 'Arms Race'?

Productivity Questions for FTTH Network Financiers

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Abstract

Fast internet access is widely considered to be a productivity-enhancing factor. However, despite promises of substantial gains from its deployment, the evidence from recent empirical studies suggests that the productivity gains may not be as large as originally hypothesised. If substantiated, these findings suggest that current government plans to apply significant sums to bring forward the deployment of fast fibre networks (e.g. in both Australia and New Zealand) may ultimately be unlikely to generate returns to the extent anticipated by their sponsors.

Drawing upon the critical literature generated when the original 'computer productivity paradox' called into question why investment in ICTs was apparently failing to generate anticipated productivity returns, this paper develops a critical questioning framework to assist policy-makers in identifying the salient productivity issues to be addressed when making the decision to apply scarce public resources to faster broadband network deployment. Using multiple literatures, the framework highlights the nuanced and highly complex ways in which broadband network speed may affect productivity, both positively and negatively. Policy-makers need to be satisfied that, on balance, government-funded investments in faster networks will likely generate the anticipated net benefits, given the significant uncertainties that are identified in the questioning framework.

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1 Introduction

Fast internet access is widely considered to be a productivity-enhancing factor (e.g. OECD, 2003; Crandall, Lehr & Litan, 2007). As faster broadband technologies become available (e.g. fibre optic cable), many governments have pledged significant sums for the upgrading of existing telecommunications networks (e.g. copper-based ADSL) to fibre-based connections, lest local firms and households are left on the wrong side of the 'digital divide'. For example, in Australia the Federal Government has pledged up to A$43 billion to build a fibre-based Next Generation Broadband Network[1]. By comparison the New Zealand government's pledge of NZ$1.5 billion is more modest, but still significant given the scale of the economy[2]. Municipal governments have also been active in funding fibre networks, for example in the Netherlands (Sadowski, Nucciarelli & de Rooij, 2009).

Advocates for increased (and arguably even speculative) government investment in faster broadband networks (often before the private sector has indicated any willingness to invest) claim substantial spillover benefits (i.e. social gains exceeding private gains) are associated with broadband investment (OECD, 2009). Such advocacy derives from Growth Theory (Romer, 1986) and General Purpose Technology (GPT) theory (Helpman & Trajtenberg, 1996). Growth theory suggests long-run economic growth emanates from spillovers arising from innovation and investment in new technologies. GPT theory (the characteristics of which Information and Communication Technologies (ICTs) and their subset broadband are widely believed to exhibit) attributes additional benefits to a class of technologies such as electricity which have been associated with substantial economy-wide reorganisation of production processes (David, 1990; Lipsey, Carlaw & Bekar, 2005).

The apparent promise of sustainable growth is no doubt appealing to policy-makers seeking to capture competitive advantages for their stewarded economies (Porter, 1990).

[1] Generally referred to as the NGBN http://www.dbcde.gov.au/broadband/national_broadband_network

[2] http://www.med.govt.nz/templates/ContentTopicSummary____41902.aspx

However, the productivity gains from GPTs often take a very long time to accrue, and it is not always obvious at the time of their initial deployment which technologies will ultimately exhibit true GPT status, at which point the maximum gains can be generated by applying additional investment, or to which point of the production process the resources are best directed. A risk exists that investment may be made in the wrong technologies (e.g. infrastructure rather than applications), or too soon to gain the best benefits. As the calls for government investment in fast broadband networks are little different from any other call for the commitment of government funds on the basis that social gains likely exceed private ones (e.g. in health or transportation), such calls should be subject to scrutiny of the same nature as would be applied to other infrastructure or technology investment proposals (e.g. electricity networks, motorways) before investment proceeds.

Prudent evidence-based policy-making ideally requires all large-budget government spending to be supported by well-regarded studies quantifying the net benefits flowing from such spending. However, rigorous research into the productivity benefits of faster broadband as consumers shift from one type of internet access to another is sparse. Most evidence (as distinct from purely theoretically-based speculation) offered in support of increased government funding is based largely upon extrapolations from extremely limited qualitative and case study analyses rather than principled quantitative research (Quiang, Rossotto & Kimura, 2009). With the notable exception of Grimes, Ren & Stevens (2009) (henceforth GRS), the assertion that positive productivity gains will be widely available from the deployment of faster (second-generation or 'frontier' – e.g. fibre-optic, VDSL) `broadband infrastructures relative to a counterfactual of widespread deployment and use of standard (first-generation or 'legacy'- e.g. ADSL) technologies remains largely an empirically untested article of faith.

1.1 Complexity and Ambiguity in the Available Evidence

To date, the body of rigorous empirical economic analyses linking productivity returns to increased broadband investment suggests that the relationship is extremely complex and highly contingent upon the presence or absence of other factors. Most empirical studies generally agree that a positive correlation exists between broadband adoption and elements of economic growth relative to a counterfactual of either no internet access at all or only dial-up access (e.g. Greenstein & McDevitt, 2009 – henceforth GM; Crandall et al, 2007). However, the results are not always straightforward. For example:

- the direction of causality is often unclear (does provision of excellent broadband access lead to better economic outcomes for regions, or do regions with better economic outcomes attract better broadband access? – Crandall, et al, 2007);
- the benefits may be diminishing as broadband penetration rises (Lehr, Osorio, Gillett & Sirbu, 2006); and
- the benefits accrued may be limited to specific user groups (e.g. Forman, Goldfarb & Greenstein (2009) find an association between US firms' internet use and wage growth for richer counties but not poorer ones).

More recent analyses of data accrued from observed patterns of broadband adoption and usage reinforce the complexity of linkages. Both GM, using United States data, and GRS, using data from New Zealand firms, suggest gains accrued from broadband investment may be substantially smaller than those projected from qualitative and case studies in the early stages of broadband deployment (e.g. New Zealand Institute, 2007; IDC Market Research, 2006). Using micro-level data from a panel of New Zealand firms to assess the effect of different forms of internet access on firm-level productivity, GRS confirms the complex and highly nuanced relationships between broadband investment and productivity gains. Firms using 'fast' broadband were found to be no more productive than firms using standard-speed broadband, even though firms using standard broadband were on average around 10% more productive than firms using dial-up internet access.

The equivocal empirical findings from the more recent studies suggest some pause for thought is warranted before governments embark upon substantial fibre investment strategies predicated upon garnering productivity benefits. As broadband is a subset of ICTs, it cannot be discounted that the empirical findings are signalling the existence of a significant disjunct between ex ante anticipated returns and ex post revealed productivity gains (i.e. a 'broadband productivity paradox') reminiscent of the much-vaunted 'computer productivity paradox'[3] associated with substantial increases in both public and private investment in computer technologies in the late 1980s and 1990s (for example, Solow, 1987; David, 1990; Triplett, 1999; Haltiwanger & Jarmin, 1999; Gordon, 2000; Jorgenson & Stiroh, 2000; Oliner & Sichel, 2000; Bosworth & Triplett, 2001; Stiroh, 2002).

The policy documents accompanying the Australian and New Zealand government proposals are short on economic substantiation, apparently confirming that little consideration has been given to the empirical evidence. Instead, they rely strongly upon aspirational objectives (e.g. 'Nation-Building' in Australia) and a fear of getting 'left behind' other OECD countries such as Japan and Korea where fibre-to-the home deployment is already widespread (e.g. in New Zealand). If GRS and GM are really harbingers of a nascent 'broadband productivity paradox', then rather than 'feeding a need for speed', the current government investment plans may instead be fuelling a financially crippling 'fibre arms race' as OECD countries seek as their primary objective to outdo each other in the speed and universality of network deployment[4], with the attendant risk that the economic benefits delivered may ultimately be disappointing given the vast sums expended.

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[3] Robert Solow's famous observation was "You can see the computer age everywhere but in the productivity statistics".

[4] The 'competition' between OECD countries to outperform each other in other network statistics, such as the number of broadband connections per capita, in isolation from other underlying economic, geographic and demographic factors that might have a bearing on relative national performance is discussed by (amongst others), Boyle & Howell (2008) and Ford, Koutsky & Spiwak (2007).

1.2 A Critical Framework for Evaluating the Paradox

In the spirit of the exploratory literature generated at the time the original 'computer productivity paradox' was identified (notably Triplett, 1999; Gordon, 2000 and Bosworth & Triplett, 2001), this paper seeks to generate a critical questioning framework to explicate the issues to be considered in assessing the (apparently contradictory) claims of large productivity gains accruing from investment in faster broadband technologies in the qualitative projections and the evidence of smaller-than-anticipated economic gains in the empirical assessments to date. This critical questioning framework can be used by policy-makers to examine a range of industry- and country-specific factors that may have a bearing upon the likely gains available from significant government investment in faster broadband networks, as well as inform future empirical research by identifying factors that will need to be taken into account in the design and testing of empirical models.

The framework will focus specifically upon the gains arising from faster broadband given that standard broadband has already been widely deployed. It thus draws most specifically upon the findings from GRS. The framework is developed by identifying first the two possible conclusions that can be drawn from the GRS results, either:

- that there are real and material productivity gains available to businesses from investment in faster broadband networks, but for a variety of reasons, these have not been able to be discerned from the study; or
- that there are few widespread, ubiquitous productivity gains available to businesses at the present point in time from investment in faster broadband networks, given the range of activities for which businesses use broadband connections and the range of applications available.

Each of these hypotheses is examined in turn, and explanations drawn from the body of qualitative and quantitative empirical literature are used to critically appraise their plausibility. As GRS examined only the returns to firms, extrapolations are made to consider the plausibility of gains in the very much more widespread residential (Fibre-to-the-Home -

FTTH) environment. It is not the authors' intention to draw an overall conclusion of which of the hypotheses is more likely to be valid, but rather to identify and explore, for both future policy analysis and empirical research, the range of issues that should be considered in assessing the likelihood of investment in faster broadband networks delivering the required objectives.

In conclusion, given the degree of uncertainty about the size and achievability of potential gains indicated in the questioning framework, and the large sums involved in deploying nationwide broadband networks, there may be some value in governments adopting the principles advocated in the literature on decision-making under uncertainty, and waiting for more evidence (one way or the other) to emerge before deciding to invest in nationwide, ubiquitous fast broadband networks.

2 Productivity Gains Are Real, But Not Detected

As a starting point, it is apposite to consider the possibility that there are real and material productivity gains to be had from deployment of faster broadband networks, but that existing studies have not detected them. Two possible scenarios warrant consideration:

- as fast broadband is such a new development and so narrowly deployed at present, it is too soon for the productivity gains to become evident; and
- methodological issues related to the design and conduct of the studies mean that the gains, although present, were not detected.

2.1 It's Too Early to Detect Productivity Gains

This scenario draws upon Triplett's (1999) suggested explanation of the computer productivity paradox that "you don't see computers in the productivity statistics yet, but wait a bit and you will". As fast broadband is still in its very early days of deployment, and broadband uptake and use is a derived demand dependent upon the development and uptake of applications that make use of fast broadband's capacities (Howell, 2003; Bailey, 1997), it is possible that to date, studies have been unable to discern productivity gains because the applications that will take advantage of the benefits of fast broadband either:

- have not yet been developed; or
- have been developed, but have not yet become widely deployed.

The latter explanation may arise because, even though applications exist, there are factors, not identified in the existing studies, that impede their uptake. For example:

- information asymmetries mean potential users either do not know of either their existence or potential benefits or take time to become aware of them and incorporate them into their production processes (Jovanovic & Rob, 1989; Greenwood & Jovanovic, 1998);
- it takes time for potential users to learn how to use the new applications, meaning the productivity gains take time to be yielded (Atkeson & Kehoe, 1997 & 2001; Goolsbee & Klenow, 1999); or
- there are other complementary investments necessary to be made to enable firms to take advantage of the benefits of faster broadband, (Helpman & Trajtenberg, 1996; Jovanovic & Stolyarov, 2000).

These explanations were commonly offered as explanations for the 'computer productivity paradox'. With the benefit of hindsight and additional research, there is now substantial evidence that productivity gains from deployment of Information and Communications Technologies (ICTs) generally require substantial complementary investments in (particularly) human and organisational capital (such as the reorganisation of production processes to take advantage of computer capabilities) to enable productivity gains to be discerned (Brynjolfsson & Hitt, 1995; 2003; Brynjolfsson, Hitt & Yang, 2002). Consequently, the gains became discernable only when lagged substantially behind the time of investment, in respect of both the ICTs and the complements (Brynjolfsson & Hitt, 2003). Moreover, it has become apparent that the gains did not emerge evenly across all sectors of the economy. For example, productivity gains to ICT investments occurred first in the ICT manufacturing sectors, then general manufacturing, and only more recently have begun to be discernable in other computer-using sectors (Oliner & Sichel, 2008).

2.1.1 Extension to Fast Broadband

As broadband technologies are a subset of ICTs, it is plausible that the same factors that delayed the accrual of discernable productivity gains from ICTs also hamper the accrual of returns to broadband investment. As fast broadband investment in particular is such a very recent phenomenon, the explanation may have some validity. As broadband has been available since the late 1990s, and New Zealand firms have generally exhibited early (over 20% of firms in 2003 – Howell, 2003) and high levels of adoption of the technology (nearly 80% of firms by 2006), the GRS findings may be offering evidence of gains accruing to deployment of the more mature (legacy) technology, but not yet to its faster (frontier) successor, as at the time of the study fewer than 10% of firms were using fast broadband connections.

However, the plausibility of this argument relies upon the presumption that the gains from faster broadband are yielded by applications that would not operate at all on standard broadband or their performance would be so substantially degraded that the potential productivity gains from the new applications' additional functionality were severely constrained. It has been cogently argued that standard broadband did offer substantial advantages of this type over dial-up because in addition to the speed benefits, which enabled the use of richer graphics than preciously available, other factors made the technology more desirable (e.g. 'always on', cost savings from not having to purchase a second phone line) (OECD, 2003).

If faster broadband did in fact engender new applications taking advantage of its specific characteristics relative to standard broadband, then it might be expected that these would be observed to emerge first in those countries where the faster networks were first deployed, and that applications used would differ in these countries relative to those countries where standard broadband only is available. Japan, Korea and the Netherlands offer live 'case studies' of such markets, as fast networks have been deployed in these countries for at least five years.

With the exception of more extensive use of gaming and ubiquitous real-time streaming of entertainment content (a predominantly residential application that would not be accounted for in the firm-level data in GRS), few new discernably different speed-dependent applications appear to have emerged in these markets (Qiang, Rossotto & Kimura, 2009). It is notable that even in the Netherlands, where substantial sums were devoted specifically to the collaborative development of applications (i.e. including users in the application design and development process)[5], the dominant applications driving residential purchase of fast networks remain entertainment-based[6]. Whilst high levels of uptake have been achieved, Sadowski, Nucciarelli & de Rooij (2009:589) describe the Netherlands experiments as "less successful in developing advanced services". Moreover, high uptake has relied upon extensive subsidies to enable consumers to purchase faster connections at the same prices offered by ADSL and cable suppliers, rather than application differences.

2.1.2 Seeking Applications and Complementarities

Looking forward, it is difficult to discern what the possible future 'faster' applications requiring faster broadband's characteristics might be, let alone the complementary investments that may be necessary to encourage their widespread deployment. For example, OECD (2009) identifies potential applications in health, education and electricity reticulation, but concedes that these applications are largely still to be developed. Whilst it cannot be discounted that new applications will emerge, equally it cannot be discounted that the current disappointing application development pattern observed in the Netherlands may continue. At the very least, it might be expected that advocates seeking funding for the deployment of new networks would offer some more detailed evidence of the nature of applications yet to be

[5] Development focused principally on of e-health, e-learning and e-church applications.

[6] Principally 'triple play' (television, telephone and broadband connection) packages.

developed that they expect the new networks to support, and some evidence that these could not satisfactorily developed and delivered on legacy networks.

2.2 Methodological Issues: Study Scope and Data Measurement

This scenario draws upon Triplett's (1999) suggested explanation of the computer productivity paradox that "whether or not you see computers everywhere, some of what they do is not counted". Whilst Triplett was referring in this instance (and also in respect of the related speculation that "you may not see computers everywhere, but in the industrial sectors where you do see them, output is poorly measured") to the collection of statistics for use in macroeconomic models measuring productivity at a national level, it is apposite to question whether the scope, methodology and/or measurement techniques of the GRS study might be failing to capture some relevant information about productivity of firms using fast broadband.

2.2.1 Study Scope

It is plausible that the scope of the GRS study may be failing to detect some of the productivity gains from the use of fast broadband. As it focuses on firm-level data, it measures only the gains that accrue to a specific firm from its own choice to adopt fast broadband technology. It is feasible that real benefits are generated by the firm's technology adoption, but that they are accrued at some other point in the value chain (Choi & Whinston, 2000) which is external to the study.

For example, a travel agent offering physical, face-to-face booking services may also offer web-based booking services. The web site may not actually make the agency more productive, as now both a physical and electronic distribution chain must be maintained (indeed, productivity will decrease if costs increase but booking numbers remain constant). However, there are very substantial gains available to a consumer, who may be able to substantially reduce search (e.g. finding a holiday) and transaction (e.g. the additional time and costs involved in physically visiting the agency to make the booking) costs by booking online, even though the price paid is identical for both service types. Such consumer benefits are outside the scope of the firm-level data collected for analysis by GRS. Indeed, they are also largely outside the scope of data collection for most national accounts measurement purposes, so have contributed to the general ICT productivity paradox, as identified by Triplett (1999), Gordon (2000), Bosworth & Triplett (2001), and others.

If the gains from firm-level investment in fast broadband are being accrued in non-measured sectors, and the gains are coming specifically from the adoption of fast broadband (as opposed to any other form of broadband), then it follows that the application, rather than the connection itself, is the key. That is, when attributing the gain to broadband connection type, it must be ascertained that the same level of gain is not available to the consumer from engaging with a firm using the same application and a standard broadband connection.

Furthermore, even if consumer gains are real and measured, it must also be ascertained that the firm cannot generate the same productivity benefits from the applications without having to maintain a fast connection itself, whether or not the consumer requires a fast connection to get the benefit. For example, reasonably static data is often fed by firms into rich, complex applications hosted at intermediaries. Whilst users of the hosted applications may require fast connections to access benefits of richness and complexity added by the intermediary, the core data may be very much less voluminous or transmitted by the firm to the intermediary only infrequently, thereby rendering fast or more capacious transmission at the firm (source) level less valuable. By way of illustration, many accommodation providers utilise aggregator sites to manage their bookings remotely rather than in-house. Whilst an end consumer may wish to browse a rich range of accommodation options, including photographs, videos and location information, only a very small quantity of information pertaining to confirmed bookings is actually exchanged between the aggregator and the accommodation supplier.

This reasoning suggests that in order to undertake studies measuring the effects of faster broadband on productivity growth, and identifying the ways in which those gains are accrued, the research design must ensure that:

- all relevant gains care captured within its scope;
- application use and broadband connection type must be considered at all parts of the value chain for all relevant parties; and
- distinctions must be made between applications, connection speed and the presence or absence of complementary investments, in order to assess the extent to which the gains can be attributed to the capabilities of the transmission mechanism, the application capabilities or other factors (Brynjolfsson & Hitt, 2003) .

Only if these factors have been reasonably addressed can it be possible to draw a reliable conclusion of either the extent of the attribution or the direction of causality to investment in increased broadband speed. This does not mean that studies such as GRS are without merit – rather, it enables their findings to be interpreted with greater understanding in order to inform investment policy formation. For example, the study offers clear evidence of firm-level gains from investment in standard broadband despite the fact that the full extent of gains may not have been captured in the study. This has been achieved using existing networks with limited government involvement in altering the incentives facing firms in their connection and application adoption processes (i.e. they have been achieved using privately-provided, largely unsubsidised networks), suggesting private gains may be sufficient in many cases to engender the relevant investment in both networks and applications, notwithstanding the fact that these networks and applications may themselves generate additional (uncaptured) spillover benefits.

2.2.2 Data Measurement

The GRS authors acknowledge that their study may not be detecting productivity gains to investment in faster broadband due to issues associated with their data definitions and measurement tools. Specifically, their delineation between 'fast' and 'slow' broadband was based upon firms' self-reported technology type, rather than actual connection speeds. Broadband-using firms reporting use of a 'cable' connection were assigned to the 'fast' group; others to the 'slow' group ('fast' broadband in New Zealand was only available to cable subscribers at the time of the study). It is possible that some firms with relatively fast ADSL connections were assigned to the 'slow' group', whilst cable subscribers on congested circuits receiving real speeds no better than some ADSL firms were assigned to the 'fast' group. This may have resulted the two groups being insufficiently indistinct for meaningful differences to be discerned.

It is also noted that GRS, whilst matching firms on a number of similar characteristics, does not make any distinctions based upon the industry sector of the firms in the study. It is conceivable that this might have masked the existence of statistically significant productivity gains in some sectors. Furthermore, in the spirit of Triplett, the sectors most likely to be using fast broadband connections – for example, finance, insurance, health, education, government – are those where it is most difficult to measure output (at least at the macroeconomic level). Even though the use of micro-data militates to some extent against the macroeconomic output measurement problems, it may not always be clear that the gains from the use of the technology are accurately captured in the financial output measures assessed. This suggests that, in addition to the factors highlighted in the preceding subsection, future studies need also to take account of the potential differences in returns in different sectors of the economy.

2.2.3 Do Limitations Invalidate the Questioning?

Methodological weaknesses are arguably a cogent reason for questioning the extent to which the GRS study alone can be relied upon in policy-making. However, they should not be used as justification to avoid questioning the possibility that the results may also have some validity. At the very least, the foregoing discussion highlights a number of ways in which future empirical research can be designed to cast further light on the question of where and how the positive gains to faster broadband investment accrue.

3 The Productivity Gains From Faster Broadband Deployment Are Limited

This section draws its inspiration from Triplett's (1999) postulation that "you see computers everywhere but in the productivity statistics because computers are not as productive as you think" and Gordon's (2000) reasoned but sceptical demand-side focused view of the productivity potential of ICTs compared to the other 'great inventions' of the past: namely electricity, the electric light and electric motors; the internal combustion engine; petroleum, natural gas and processes that 'rearrange molecules'; running water, indoor plumbing and sanitation services; and other entertainment, communications and information innovations such as the telegraph, telephony, radio and television. The extended analogy questioned here is that 'some may wish to see faster broadband everywhere, and it may have been portrayed as having great productivity benefits, but will it really be as productive as its promoters have claimed it will be?'

The focus on a wide-ranging demand-side view of the technology in this section is warranted as, to date, most calls for government investment in faster broadband networks have been championed principally by supply-side interests (e.g. content, equipment and network providers) and small subsets of users (e.g. early adopters), whose current and aspired future demands on the network may not be characteristic of the wider demand-side body. It has to be questioned whether the valuations these champions have placed on the benefits from adopting broadband of any speed or quality can be reliably used in the assessment of benefits arising from ubiquitous deployment of faster networks.

As the GM and GRS studies use observations drawn from populations (GM) and representative samples (GRS), the potential for biased valuations skewing results has been minimised. That these analyses, based on actual demand-side valuations of the benefits of the technologies, have found the benefits from broadband (and fast broadband in particular) deployment to be much less than those projected from speculative studies means they could be legitimate harbingers of much lower user valuations of the benefits of faster broadband networks amongst the wider population than their inventors and promoters might wish.

Drawing upon the issues addressed by Gordon and Triplett in their assessments of the plausibility that ICTs were not as productive as their protagonists initially thought they might be, this section poses five pertinent questions:

- are the returns to investment in broadband speed diminishing?
- are observed gains simply one-off adjustments or evidence of the creation of sustainable growth engines?
- how important is the broadband network in the production value chain?
- do broadband networks affect productivity by altering the composition of firms within the economy – i.e. altering the balance between existing exporters (the intensive margin) and new exporters entering the market (the extensive margin)?
- are externalities created that detract from the benefits accrued?

These questions are now addressed in turn.

3.1 Are Returns to Investment in Broadband Speed Diminishing?

The seminal message of Gordon's analysis of the computer productivity paradox is his assessment of the effects of the declining real cost of computer power and the consequent pervasiveness of decreasing returns (pp 60-71). He argues that unlike the other "great inventions" (his term for GPTs) of the past, for ICTs, the costs of production have fallen faster than the gains in utility from the development of new computing characteristics, resulting in the classic pattern of decreasing returns. Gordon argues that for the other 'great inventions', new applications tended to lead to higher production costs, but as the welfare gains generated were even greater than these additional costs, and diffusion occurred regardless of the higher prices charged for the goods, the welfare gains were substantially larger.

3.1.1 Marginal Gains vs Marginal Costs

Gordon illustrates his point by comparing the marginal gains in word processing utility from the first invention of the memory typewriter, via the development of successive versions of WordPerfect and Word For Windows, illustrating that the marginal gain in utility from each new variant was successively smaller, even though each required significantly greater amounts of computing resource in order to generate those benefits. Only the rapidly decreasing cost of producing the additional computing resource rendered it feasible for end users to purchase the increasingly more complex new computers required to operate the new applications, given the increasingly smaller marginal utility gains from each iteration of software development[7]. He also notes that the applications used most often by firms in 2000 were in large part the same ones deployed in the earlier days of computing – word processing, spreadsheets, financial management and stock control.

In a similar vein, it might be argued that the greatest gains to users in the information transportation component of the ICT industry have already been garnered from the creation and deployment of dial-up internet access, and to a lesser extent, the earlier, slower variants of broadband, simply because they made available the benefits of applications – such as email and web browsing - that were previously infeasible and for which the substitutes were extremely costly. Whilst subsequent developments have increased the richness of the graphics employed (and increased the capacity required of both the transportation infrastructure and the computing resource at each end), the basic applications remain functionally equivalent.

For example, Facebook and Twitter are richer extensions of email, enabling instant written communication between individuals. Using Gordon's logic, the marginal benefit to their users compared to simple email pales in comparison to the marginal gain experienced by the first email users, whose messages were transmitted in a matter of minutes rather than the

[7] Whilst this example is argued on the basis of a single application, it is recognized that the net benefits for most users would have been derived from a bundle of applications, all undergoing the same sort of incremental innovation, but at differing rates and times.

days required for a standard post letter. And whilst there is arguably benefit to be had from the increasing richness of graphic content and menu choices offered (often provided simply because cheap capacity is available and technological development makes it possible), Triplett observes that "making choices is costly, so I do not want to be forced continually to choose from a wider menu". Moreover, the simple availability of an application does not guarantee that it will be widely valued or used: "for a large number of car buyers, the Model T proved good enough, they did not need to be on the technological frontier, even if some other buyers wanted the best that could be obtained".

3.1.2 The Marginal Value of Time

Put simply, physical post, email, Facebook and Twitter are applications–albeit facilitated by transmission infrastructures of varying capacities and capabilities. Faster broadband increases the value of these applications only insofar as the value of the time saved in making the actual transmission[8] of information, assessed at the user's marginal valuation of time. Varian's (2001) INDEX studies suggest that there are very large variations in individuals' (and by extension, firms') valuation of time, depending upon whether it is paid or leisure time, the nature of other tasks the individual is engaged in and the time criticality of the applications used. Importantly, Varian finds that, when empirically tested, individuals' marginal willingness to pay for faster internet speeds is generally very low. This appears to be borne out in multiple customer satisfaction surveys, even as the speed of standard broadband offered has increased (e.g. Horrigan, 2006).

To assess the demand-side effect of investment in faster broadband in relation to applications, the marginal benefits to users of transmitting the same information at a faster speed (say 100Mbps) than a slower one (say, 10 Mbps) must be considered, relative to the higher cost of the faster service. If the majority of internet use is confined to existing applications, the individual time savings from the faster connections are likely extremely

[8] 'Transmission' as it is used here refers to both the sending and receiving (i.e. transportation) of the information.

small. The time benefits from transferring existing applications onto faster networks will make the substitution feasible only if the user's valuation of time is sufficiently high enough to offset the additional cost. Thus, only new applications or those that are critically dependent upon the faster speeds or where timeliness is highly valued will justify the additional expense to users of substituting from existing networks. As indicated in OECD (2009), most of these remain yet to be developed, despite substantial investments in research and development (Sadowski, Nucciarelli & de Rooij, 2009). The marginal benefits from the vast number of existing applications currently being used will almost certainly be small (and decreasing) with increasing in transmission speed.

3.2.3 An End to Endlessly Decreasing Marginal Network Infrastructure Costs?

Unlike the case of computers and ICTs in general, where real costs decreased inexorably over time, the costs of increasing transmission speeds are, in the medium term at least, likely to be increasing as a function of the qualities delivered, as completely new networks with high fixed and sunk costs must be constructed to carry traffic at the faster speeds. This contrasts with the history of network costs to date, where faster speeds have been made possible by making incremental improvements to existing networks, the costs of which had been largely sunk in order to meet historic application demands (voice and broadcast television), (the pattern that occurred with ADSL and some cable networks). Given the likely scenario of increasing real network costs (including the costs of maintaining duplicate networks as some users persist with ADSL or slow cable connections, even though FTTH is available), without the development of a substantial number of highly-valued, widely-used new applications that cannot be satisfactorily delivered on legacy networks[9],

[9] It is noted that the use of video streaming cannot be viewed in isolation as a completely new benefit brought about by the deployment of fast fibre-based networks. The benefits of these technologies must be considered as marginal gains relative to the consumption of video entertainment via other mechanisms, such as broadcast television and the purchase or hiring of DVDs and BluRay discs, and downloading via existing standard broadband connections. Only if the marginal benefits exceed the marginal costs, will users switch from their existing methods to fast broadband connections.

there may be insufficient benefits available to offset the higher costs of faster network deployment, at least in the foreseeable future.

3.2 One-Off Returns or Sustainable Growth?

In a similar, but related vein, Lehr et. al (2006) report decreasing productivity returns as broadband penetration increases. This is the typical result from the diffusion of a technology where the early adopters are the highest-valuing, and the later adopters (‘laggards’) are the lower-valuing ones. If new applications and increasing use of existing applications were generating increasingly higher returns for existing users, and the same applications were drawing new users to the technology in order to accrue the benefits available, then productivity returns would be closer to constant, or even increasing (Bailey, 1997). As standard broadband exhibits decreasing returns both in application benefits and increasing penetration, new application development is weak, and fast broadband users are most likely to be existing broadband users upgrading to faster broadband, then as faster broadband becomes more widely deployed, it would also be most likely that similar decreasing returns would be observed on the faster networks as well.

That decreasing returns is the norm for standard broadband suggests that for many firms and individuals, broadband-based applications represent opportunities to make one-off investments in a small number of applications, rather than offering a means of generating increasing firm-based returns on an ongoing basis. However, this is not necessarily surprising. Many non-economic commentaries appear to assume that, as the goods that characterise the information age themselves individually exhibit increasing returns (Quah, 2003; Arrow, 1999, 1962), the technologies that aid their production might also behave according to different economic rules – notably by defying the classic economic assumption of decreasing returns. Simple economic analysis, however, shows this assumption is flawed. Most of the technologies and applications supporting the creation of information goods are essentially rival, excludable goods, albeit exhibiting some network effects and economies of scale (Shapiro & Varian, 1999)[10]. This distinction is material for assessing the productivity potential of networks and applications.

Productivity growth models (e.g. Romer, 1986; David, 1990) require that gains as a consequence of an investment in one time period lead to even higher gains occurring in subsequent periods. Triplett (1999) illustrates this with a simple numerical example, which lends itself to extrapolation to Gordon's word-processing example. If adoption of an application generates a gain of $10 over the expected $100 without it, the gain is 10%. But in the next period, to maintain a 10% growth total income must be $121, not $110. So, Word may make me more productive as a report writer in the year I adopt it (e.g. I can type 11 reports instead of 10), but unless the same investment makes me even more productive in the next year (i.e. I generate a further $11 of output by typing 12.1 reports rather than 11), I will revert to having a 0% growth rate. Triplett uses this reasoning to support the contention that "there is no paradox: some economists are counting innovations and new products on an arithmetic scale when they should count on a logarithmic scale".

By comparison, however, if I use Word to create an information good (e.g. a novel) which costs me $100 of effort in period one, but I can sell many (costless to reproduce) copies of it in more several subsequent periods, then after I have recovered my outlay, I have access to increasing returns. It is the novel, not the Word application or the transmission network that confers upon me the benefits of increasing returns (Shapiro & Varian, 1999). However, the benefits of increasing returns from my novel are recorded in productivity statistics only

[10] For example, the computer on which I use Word cannot be used by someone else whilst I am using it – therefore it is a rival good. Likewise, even though Word software is an information good (as per Quah, 2003 it can be costlessly duplicated, and all of its costs are in the creation of the original copy) that may generate some of the benefits of increasing returns for Microsoft, my own copy has been granted rival good status by the licensing agreement that precludes me from sharing it with other users on their computers. My computer and my copy of Word therefore grant me no more special benefits of increasing returns than if my tools were a pencil and paper. It has always been my (rival and excludable, short of 'cloning') knowledge, experience and creativity that has enabled me to create research (an information good) to add to the body of knowledge. To paraphrase Triplett, 'Word has not made me any smarter'. Moreover, the network over which I acquire information about other research and share my own work also exhibits rival characteristics at the margin, as my use of it creates 'congestion' that detracts from other users' benefits derived from use of the network.

insofar as individuals are prepared to pay a positive price for the novel. Whilst I can create such a good, it has to be worth my effort in creating it. If I fail to sell enough copies to break even, then I have actually contributed to a reduction in aggregate measured productivity[11].

Whilst faster broadband networks may enable movement of the inputs and outputs of the production processes used for information goods, the vast majority of goods produced in the economy remain tangible, standard goods exhibiting decreasing returns rather than information goods with increasing returns capabilities. If new applications are adopted only to support the ongoing creation of standard goods, then the productivity gains from adoption will be one-off rather than sustainable (i.e increasing returns). Without the introduction of new applications, shifting applications already in use to faster broadband will also similarly generate only a one-off benefit, but one much smaller than the original adoption on standard broadband, as it is only the marginal benefit to speed, not average benefit from initial adoption that is accrued. Unless faster networks can, of themselves, engender a change in the mix of products made in an economy or accelerate the diffusion of knowledge embedded in the goods already produced (as per growth theory), then the decreasing returns observed by Lehr, et. al (2006) in respect of standard broadband networks are not only likely inevitable, but will possibly set in earlier on faster broadband than was observed on standard broadband.

3.3 Broadband in the Production Chain

This scenario draws on Triplett's contention that "you don't see computers everywhere in a meaningful economic sense (because) computers and information processing equipment are a relatively small share of the capital stock". Whilst without doubt the ICT share of capital stock has increased markedly since Triplett made his observation, it is nonetheless true that the 'communication' portion of both the ICT stock and ICT's share of

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[11] It is noted that, by classic theories of monopolistic competition for differentiated goods, if the sunk costs of creation become sufficiently low, then 'too many' information goods may be created, as each creator fails to take adequate account of the effect of their 'creation' on the residual demand curve left after they have entered the market to sell their good. Fewer goods are sold than were created, and the uncompensated sunk time and effort expended in the creation of those that did not sell becomes a loss to the economy and a drag on measured productivity growth.

the total capital stock still remains small. Furthermore, broadband is essentially a transportation mechanism, albeit one that transports information. For most production processes, the transportation of input materials and carriage of finished goods of all kinds – both physical and informational – comprises only a small proportion of production costs.

3.3.1 A Small Change in a Small Cost Has a Very Small Effect

Where the vast majority of inputs and finished products are physical, then the proportion of those costs that can be attributed to broadband-based transportation may be very small indeed. Even the quantities of information required for marketing, shareholder communication and other information-rich tasks comprise only a small proportion of the value-added for most firms (the notable industry exceptions being health, government, education and FIRE – fire, insurance and real estate). Thus, a small change in the costs (or a small increase in the benefits arising from) of a factor that is only a small proportion of the production process may render a very small effect on productivity– and arguably one too small to be discerned in the productivity statistics. By analogy, a faster vehicle may save time on journeys, but if very few journeys are made or the average journey is very short, the savings may be too small to be significant – and too small to justify the additional cost of the vehicle[12]. However, the savings may be very much more material for a long-haul delivery firm.

3.3.2 Which is the Genuinely Scarce Resource?

Furthermore, drawing on production control literature, faster information transmission may not make much difference to overall productivity if the resources that process the transported information prior to its dispatch or subsequent to its arrival are scarce. Both Triplett and Gordon identify that for ICTs in general, it is more often than not the human component of the production process that is the bottleneck. Moreover, human-mediated processes are the ones that have, to date, proved most resistant to computerisation (and hence

[12] Unless, of course, the purpose of its purchase is a status effect (e.g. to 'keep up with the Joneses') rather than an economic decision.

digital transmission). Co-incidentally, the e-health and e-learning applications that have so far proved elusive to fast broadband application developers are also those whose existing production processes rely very heavily on human intervention.

Gordon goes on to cite Herbert Simon's aphorism "a wealth of information creates a poverty of attention" (p 69), and observes that "the brown UPS trucks are thriving with e-commerce, but each truck still requires one driver". Even when the contents of the UPS truck can be digitalised and transmitted by (fast) broadband, human logjams limit the extent of the benefits available. A fast-broadband analogy to Gordon's UPS trucks might be that 'as many high-definition movies as the connection enables can be streamed simultaneously to my home, and even though I may have a plethora of devices (computer, telephone, television, iPod, etc.) upon which each movie can be viewed, I can still only watch one of them at a time'.

In the absence of applications addressing the human bottlenecks, it is far from clear that the gains from faster broadband deployment will necessarily be as large as has been anticipated. Prudent policy-making should therefore take into account the rate of application development in key areas before committing to network investment, especially in regard to health and education applications.

3.3.3 Not All Bits Transported Are Valued Equally

Fast broadband offers functionality in respect of both the volume of data that can be transmitted and the time taken to transmit it. Whilst large-capacity networks can enable real-time transmission of all data, this requires building networks capable of meeting maximum simultaneous demand expectations at peak times. However, it does not necessarily follow that all data transmissions are time-critical, or that it should be assumed that network deployment must proceed upon the (patently flawed) assumption that all messages are equally time-critical.

In normal transportation infrastructures, choices can be made to transport non-time-critical cargoes at low-demand times, in order to relieve congestion and make better utilisation of existing assets. For example, even though one-hour couriers and air freight exist, such transportation mechanisms tend only to be used for highly-valued, time-critical movements. For the balance of movements, daily couriers and sea transport may suffice, so long as there is adequate storage on site to hold the goods delivered until required for production. Such reasoning begs the question of why broadband-based information transportation should be considered any differently from all other forms of transportation that have preceded it, from camels in the desert, canals, railways, and mail to telegraph and telephony. The question turns once again on identifying the truly scarce (or costly) resource.

Just-In-Time inventory management, that makes extensive use of computerised information transmission to co-ordinate physical stock movements, became commonplace because for most physical production processes using bulky inputs, inventory storage space (amongst other costs) was more expensive than physical transportation, making the time of delivery a critical factor in the total cost function. By comparison, decreasing computer costs have made digital storage extremely cheap. Whilst transmission costs have fallen over time, it might be argued that transmission is still (relatively) dearer than storage[13], and with the impeding development of new (and potentially duplicate) networks, may become relatively more expensive, at least in the short-to medium term, until the fixed costs of new networks are largely recovered by investors.

Although ‘cloud computing’ presumes remote storage of data accessible on demand, delivered nearly instantaneously by ubiquitous fast broadband networks, in practice, considerable local caching of data already occurs in order to reduce the transportation costs of commonly accessed material. It therefore begs the question of where it is optimal to store data, trading off both storage and transmission costs, and how this affects the optimal time to invest in new, costly (and faster, more capacious) transmission networks. If all data must be moved on demand in real time, then networks must be able to meet maximum simultaneous

[13] Indeed, if they were not, then there is no economic justification for the currently-observed extensive use of web proxy servers.

demands. This will require the network to be more capacious than if the demand is more evenly spread or data is stored locally.

Consequently, peak and off-peak charging is common in most network industries, enabling users to make efficiency-enhancing choices about the value to them of the timeliness of network use compared to the cost of caching (i.e. on a computer hard drive or firm server rather than at a distant host). The benefit for network operators is that with time-sensitive pricing and low-cost local storage, existing infrastructure can be more efficiently utilised, putting back the time at which more capacious (and more costly) networks must be built relative to the 'simultaneous demand' model. Moreover, if the costs to consumers are lower from using alternative methods of interaction (e.g. personal storage) than mandatory real-time access (e.g. real time cloud computing), then no matter how capable the networks are, it is likely that economic imperatives will prevail (e.g. the predominance of text messaging over mobile voice calls in New Zealand where mobile voice calls are comparatively expensive).

3.3.4 Underpinning Assumptions: Aspirational or Evidential?

It is apposite for policy-makers to consider whether calls for investment in faster, more capacious networks at the present time are predicated upon particular 'world-views' of idealised future network use that differs substantially from current usage patterns rather than economic considerations at both the network operator and user levels and observed behaviours in both legacy data transmission and other transportation and network infrastructures. These espoused views may not match the realities of actual use, which ultimately will be determined more by economic realities than idealistic objectives requiring substantial behavioural changes that do not necessarily appear to follow the historic or existing pattern of economic incentives.

3.4 Intensive vs Extensive Margins

The prior analysis in this section is applicable mainly to existing firms in existing industries within a country. For instance, the analysis in section 3.2 analyses situations in which an existing firm may obtain a one-off jump in productivity without any accompanying change in the ongoing productivity growth rate. It is possible that the introduction of fibre and other fast forms of broadband may also change the composition of firms within the economy.

To analyse this issue, we draw on the insights of trade theorists who emphasise the difference in exporting outcomes arising from the *intensive* margin versus the *extensive* margin. For instance, Hummels and Klenow (2005) find that not only do large countries tend to export a greater quantity of a given good than do small countries (the intensive margin) but they also export a wider set of goods (the extensive margin). The latter margin accounts for around 60 percent of the greater exports of large countries; thus concentration only on the intensive margin may lead to distorted interpretations of trade behaviour in the presence of policy and technological changes.

Chaney (2008) applies this insight to the behaviour of exporters within a model incorporating imperfect competition, heterogeneity in productivity amongst firms and fixed costs of exporting. In this environment, a reduction in transportation costs or in the severity of trade barriers not only changes production by existing exporters (the intensive margin), but also enables new exporters to enter the market (the extensive margin). A corollary is that a reduction in trade barriers or transport costs reduces exporters' average productivity since formerly less productive firms that were not initially in the market now enter the market, dragging down the aggregate productivity of exporters.

We can apply these insights to analyse extensive margin effects of a national investment in fibre. Consider a set of firms that: (a) make a global (or regional) location decision that embodies sunk costs, and (b) are current users of substantial amounts of digital traffic; thus faster and more reliable broadband facilities reduce their overall cost structures for given output. We will refer to these firms as digital intensive firms, or DI-firms.

In these circumstances, fibre investments become a form of trade barrier affecting this set of firms; the investment acts in a similar manner to an export (or import-competing) subsidy. If a country that competes with the domestic country for DI-firm location invests in a comprehensive fibre network, some DI-firms that may otherwise have located in the domestic country will instead locate in the competing country. Domestic employees (with skills sought by DI-firms) who would otherwise have been employed in these firms may migrate to the competing country to obtain employment. Their wages and taxes will be lost to the domestic economy; this loss will be particularly acute for the local economy where there is complementarity between high-skilled (and highly remunerated) occupations and DI-firms.

In addition to current DI-firms, the location of other firms that are currently not digitially intensive may also be affected by a fibre investment. In the presence of high sunk costs, a firm has to make its location decision with respect to a long time horizon. Over this horizon its own need for fast broadband services may change in unknown ways as other technologies and demand patterns change. In the presence of this uncertainty, the firm may effectively take out an option over future technologies by choosing to locate in a country that has a proven record of investing in fast broadband technologies. Thus even though its current productivity may not be altered by the presence or absence of a fibre network, it may still choose to locate in an economy with a proven fibre network. In the same way as the extensive margin dominates some aspects of trade behaviour, it may therefore also play an influential role in the global location decisions of firms with current or even uncertain prospective demand for fast broadband services.

Given these considerations, there is the prospect of a global fibre-war (analogous to a trade-war) in which fibre investments are used as a type of export subsidy (trade barrier). Modern trade theory shows that in the presence of imperfect competition and fixed costs, a trade subsidy may in some circumstances be an optimal response to other countries' policy choices. Applying these insights to fibre investments, if a competing country decides to invest heavily the optimal response may be for the domestic country also to invest so as to maintain level pegging; and if the competing country chooses not to invest, the optimal response may still be to invest in order to 'steal a march' on the competing country. Thus investment in fibre is the Nash equilibrium outcome.

However the benefits of investing must, as always, be weighed against the costs. The latter are relatively easy to measure, but the benefits arising from the extensive margin based on location choices is exceedingly difficult to calculate, in part because the eligible set of firms includes offshore entities and entities that may not yet even be in existence. Nevertheless, because of the game situation that exists between rival countries, coupled with the presence of sunk costs, a policy of 'wait-and-see' (i.e. the typical policy prescription in a situation of investment under uncertainty) may not be optimal. In order to inform these inherently difficult decisions, empirical work is required that examines the impacts that recent fibre (and related) investments have had on firms' global location choices, differentiating between firms that are currently digitally intensive and those that are not. To the authors' knowledge, little such work is yet available on this topic.

3.5 Externalities: Negative? (Un)expected?

Most government spending proposals are prepared by stakeholders with strong motivations for a project to proceed, and therefore are more likely to overstate the benefits and understate the costs. Even without this systemic benefit-cost inflation, as a consequence of bounded rationality it is unlikely that all of the possible consequences (both positive and negative) associated with a project will be foreseen. The unforeseen consequences may be either positive or negative. Whilst the negative consequences are costly, and the unforeseen ones unavoidable, prudent decision-makers should make a critical assessment of the proposal and try to anticipate which largely foreseeable costs and externalities have been omitted.

In respect of ICT projects in general, Gordon asserts that four possibly unanticipated effects have resulted in less-than-impressive productivity returns on ICT investment, even though businesses and consumers eagerly embarked upon the purchase of computers and internet infrastructure and the creation of entire new industries. These are:

- computer investments made to protect market share or aimed at taking customers, profits and capital gains away from other companies is essentially a zero-sum game; redistributions of this nature are not wealth-creating;
- much internet content is not reflecting truly new economic activity, but simply translates existing activity into an electronic medium (e.g. web sales replacing catalogues). Whilst one-off gains are created (see 3.2 above), these are marginal gains on old activities, not the creation of new sources of wealth;
- new technologies may lead to productivity-reducing duplication of existing processes (e.g. the travel agent example above) rather than substitution; whilst convenience may have value for some, it may lead to higher costs for those who know what they want, and have to pass through additional menus to access what was previously directly acquired; and
- productivity on the job may be impaired by the growing use of business computers with continuous web access for personal consumption purposes.

All of these points are equally applicable to broadband networks (as discussed in the preceding sections) and all warrant consideration in the process of deciding whether it is more appropriate for the government, or the private sector to take the lead (and bear the consequent risks) of faster broadband deployment.

4 Conclusion

The preceding sections have laid out a critical framework for systematically thinking through the issues raised by recent studies suggesting the productivity gains to faster broadband deployment may be smaller than has previously been suggested. The framework draws heavily upon the same sort of critical thinking that was generated when the initial productivity returns to computer investment proved more elusive than had been originally anticipated.

Whilst many arguments have been posited, it is not the purpose of this paper to suggest what weight should be placed on all or any of the contentions, both positive and negative, discussed. Rather, the purpose of the framework is to highlight the complexity of the problem facing government policy-makers and decision-makers when assessing the costs and benefits of applying government funding to such projects. The ways in which ICTs in general, and broadband networks in particular, contribute to economic performance, are many, varied, highly nuanced and many of the factors interact with each other in ways that make it extremely difficult to predict the likely outcome. Ultimately, it is the role of policy- and decision-makers to place their own weights on each of these issues, as determined by each in the context of their own projects.

There will always be risks associated with investing in a project where there are so many unknown factors. Modern risk management theory suggests that when more or better information will materially reduce the risks, the optimal strategy is to either invest in more information acquisition or wait for more information to be revealed before committing. This is no less relevant for public sector investors than private sector ones. Relevant information may include, perhaps, the propensity for the private sector to invest in faster networks in those areas where the private gains are sufficiently large that it is unnecessary to commit public funds, thereby freeing up public funds for those segments of the market where the private sector is unwilling to invest, or where gains have already been proven to exist, but which still have to be realized (e.g. those segments of the market that do not have access even to standard speed broadband networks). Policy-makers may be able to reduce the uncertainty by commissioning more research, in order to develop greater understanding. The questioning framework of this paper can assist in the design of that research, as it highlights some of the questions that existing research – both empirical and qualitative - has itself raised. The authors of this paper look forward to the opportunity of contributing to that uncertainty-reducing research endeavour.

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