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Economic Impact of Broadband: An Empirical Study

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1 Introduction and Executive Summary

1.1 LECG has prepared this report for Nokia Siemens Networks on the economic impact of broadband as part of a broad agenda of research related to Connectivity Scorecard 2009.[1] The purpose of the Scorecard was to provide a benchmarking of countries according to how "well" these countries are using Information and Communications Technology (ICT) to promote economic growth and improve business productivity. The Scorecard deliberately took a broad and holistic look at many aspects of ICT—not just the deployment of infrastructure but also the usage levels of key technologies, and ICT skills in the workforce and the general population.

1.2 As the Connectivity Scorecard was disseminated, the type of question that we were frequently asked is "how come my country finishes so low on the Scorecard and the United States finishes so high—after all, broadband here is much better than in New York?" We answered this question by suggesting that we were looking at Connectivity very broadly, and there was more to Connectivity than just broadband. Nevertheless the specific interest in broadband sparked two major questions:

- Is there any way of measuring how much broadband is worth?
- Does the impact of broadband vary with other attributes of the "ICT eco-system" in a country, as the Connectivity Scorecard suggests it should? [2]

1.3 This document reports the findings of an econometric investigation into the impact of broadband on productivity growth in 15 OECD nations, 14 European nations and the United States. The list of countries included in the sample is provided in Table 1. Details of how we estimated our model, and the detailed economic and econometric considerations that we encountered, are to be found from Section 2 onwards. In this executive summary, we provide a high level account of our major findings.

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[1] See www.connectivityscorecard.org, for a description of our efforts to date.

[2] In the economics literature, there has been a fair amount of attention devoted in recent years to "complementary investment" or "complementary capital" as a factor that governs how effective ICT investments are likely to be. There is a consensus forming that successful ICT adoption—i.e., ICT adoption that boosts economic growth and productivity—is likely to require significant levels of complementary investment.

Table 1: Countries included in analysis

Country	Rank by Average PC Penetration, 1998-2007	Connectivity Scorecard 2009 Ranking
Austria	Medium 1/3rd	Not Ranked
Belgium	Low 1/3rd	17th
Denmark	High 1/3rd	3rd
Finland	Medium 1/3rd	11th
France	Medium 1/3rd	15th
Germany	Medium 1/3rd	13th
Greece	Low 1/3rd	24th
Ireland	Medium 1/3rd	12th
Italy	Low 1/3rd	19th
Netherlands	High 1/3rd	4th
Portugal	Low 1/3rd	22nd
Spain	Low 1/3rd	21st
Sweden	High 1/3rd	2nd
UK	High 1/3rd	6th
USA	High 1/3rd	1st

Source for PC penetration data: ITU World Telecommunications Indicators, 2008.

1.4In this report, "broadband" is measured in a particular way (the number of broadband lines per 100 population), but the "broadband" measure that we use is really a proxy for the spread of high-speed networking into the wider economy. That is, while available data reflect mostly the penetration rate of residential broadband offerings (such as cable and DSL) higher penetration rates of such technologies are likely to be quite correlated with the spread of other types of networked ICT, such as businesses using dedicated access lines with very high throughput potential for Wide Area Networks (WANs). Broadband represents the ultimate marriage of the personal computer and the telephone line.

1.5There is little doubt that the effects of the Internet, of broadband, and of high-speed networking on the way that business is conducted have been profound. But careful measurement of such effects is difficult: richer countries have more broadband, and broadband has actually diffused faster in countries that were rich to begin with; yet richer countries have not necessarily experienced faster rates of economic growth than relatively poorer ones. Broadband was generally introduced earlier in richer countries than in relatively less rich ones.

1.6As with many other aspects of economic growth, there are “chicken and egg” issues at work here, none of which are particularly easy to address. Yet after addressing them as adequately as we were able to, we have found that while the impact of broadband on productivity growth (economic output for every hour of labour) might be quite large, this large impact of productivity growth is not universal.

1.7Specifically our econometric work suggests the following:

- Countries that had, and continue to have, high levels of general ICT diffusion[3] have been faster to adopt broadband and the broadband that has been added seems to have produced quite significant productivity gains;[4]
- The econometric model that we have developed predicts that an increase of 1 percentage point (1 more broadband line per 100 individuals) in these “medium or high ICT” countries increases productivity by 0.1%. The implications of this type of productivity gain are shown in Table 2, which suggests the increase in GDP (holding constant the number of hours worked) from an increase of 1 percentage point, 5 percentage points and 10 percentage points in broadband penetration;
- However, countries (mainly in Southern Europe) that fell, and continue to fall, in the group of countries with low general ICT diffusion, have been slower to adopt broadband, and the broadband that has been diffused does not appear to have had a productivity impact;
- In fact, our results suggest that in such “low ICT” and “low broadband” environments, the marginal benefit from adding broadband lines might be essentially zero. It may be the case that as broadband penetration in such countries grows it will itself create the “ICT eco-system” that we think is required to realise significant and wide-reaching productivity gains from

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[3] We divided our countries into three groups of five countries according to the average level of personal computer penetration (PCs per 100 population, as reported by the International Telecommunications Union’s World Telecommunications Indicators database) over the period 1998-2007.

[4] These benefits are most likely the result of the interaction between broadband and the existing stock of ICT capital, ICT technologies and ICT-complementing capital in these countries.

broadband.[5] This is an "if you build it, they will come" view of the world, and we do not think that it is necessarily incorrect—in this case, the productivity benefits of broadband may appear in the course of time;

- However, there are other important characteristics of the ICT environment (and of the wider economic environment) in these countries that likely have played a role in retarding the pace of broadband adoption. The productivity benefits of ICT are best realised when there is sufficient investment in complementary factors such as "re-skilling" of the workforce and general population, and an environment is created where the costs of technology adoption are minimal. By addressing at least some of these complementary factors, governments in such countries might be able to accelerate the pace of broadband adoption, as well as deeper and more economically effective use of broadband, and thus realise productivity benefits from broadband more quickly and more completely.

IMPORTANT NOTE: The discussion of benefits here refers to what economists call "spill-over" benefits, the effects of networked ICT on raising productivity across the economy. However, increased investment in broadband will in any event have a growth-promoting effect, because more investment means more GDP.

Table 2: Impact on GDP for each additional broadband line per 100 persons (2000 US dollars)

Country	1 additional line	5 additional lines	10 additional lines
France	1,769m	8,846m	17,692m
Finland	157m	783m	1,567m
Germany	2,023m	10,115m	20,229m
Sweden	274m	1,368m	2,736m
UK	1,845m	9,225m	18,451m
USA	11,528m	57,640m	115,280m

1.8The results from our work appear quite consistent with some of the previous literature on telecoms, ICT adoption and technology adoption. Our message here is that broadband is a good thing, potentially a very good thing, but it is not a "magic bullet" solution for economic growth or productivity. Table 3 summarises

[5] For example, if people are interested in subscribing to broadband service, then they usually would have to buy a personal computer or other device to access broadband. This will raise the demand for personal computers, encourage people to acquire PC literacy, encourage businesses to offer more products and services via electronic means and generally encourage a more "e-friendly" environment. However, all of these developments take time. In a country where businesses and individuals were already "e-friendly", adding broadband to the mix of available technologies may have resulted in a powerful effect of "joining up" the various technological elements that were already in place, resulting in a more immediate and more profound impact of broadband.

the literature on telecoms, ICT and broadband to date. In particular it is interesting to note that the “Net Impact Study” (Varian et al.) in 2002 predicted that between 2002-2011, “Internet Business Solutions” would add roughly 0.43 percentage points per year to the annual growth rate of U.S. productivity. Our model suggests that on average the addition of broadband to U.S. productivity has been about 0.25 percentage points per year between 1999 and 2007. During this period, average annual productivity growth in the US has been about 2.1 percent per year, implying that the “broadband effect” is 1/8th of all productivity growth. While our term “broadband” really refers to the spread of high-speed networking into the economy and the Net Impact Study focuses much more narrowly on Internet, the comparison is interesting.

Table 3: Key Literature and Findings

Type of study & key findings	Key authors
Study of fixed line telecom impact, 1980s & 90s - telecoms penetration drives economic growth - spill-over benefits allow business to be done over long distances	Norton, Röller-Waverman
ICT studies, 1990s & 2000s - ICT has a significant impact on business productivity in the US - European and Canadian data fail to show the same positive effect - there is a lag as firms need to invest in complementary capital and work habits need to change	Jorgenson, Stiroh
“Forward-looking” broadband studies - the net present value of additional economic output as a result of broadband deployment would be several hundred billion dollars and hundreds of thousands of new jobs - Internet Business Solutions (IBS) may contribute 0.43 percentage points a year to US productivity growth in 2002-11	Crandall, Jackson, and the “Net Impact Study”
Econometric studies of broadband - strong evidence that broadband drives employment in ICT using sectors - some studies fail to find a positive significant relationship between output and broadband deployment and there may even be a negative relationship - some evidence that there is a positive relationship between broadband deployment and economic growth especially after a critical mass of broadband lines is reached	Crandall, Litan, Lehr; Koutroumpis; Thompson Jr and Garbacz

Policy implications

OECD nations

1.9For the richer countries, the ones with the higher levels of ICT predisposition, broadband has already made a difference to their economic fortunes. Such countries have some advantages: generally better-educated workforces, generally better-funded university systems, and generally higher levels of investment by governments and businesses in research and development. They are either able to innovate themselves or to quickly take advantage of innovations such as broadband and computers. Innovative use of new technology like broadband is an important source of comparative economic advantage for such countries.

1.10As Connectivity Scorecard 2009 demonstrates, however, there is still significant potential for maximising technology usage even in the richest and most ICT-intensive nations. The United States, for instance, performs very well on most ICT metrics, but comparatively less well on broadband penetration. Given that the US already has many of the complementary features required to take full advantage of broadband, the country could gain considerable economic benefit from providing the right regulatory and policy environment for continued (and indeed accelerated) deployment of broadband networks. Additionally, the US is starting to lose its historically high ranking in university attendance and other measures of human capital attainment. It may thus have to take pro-active measures to make sure that it remains at the forefront of innovation and technology adoption, since its strengths in these areas have been major sources of its economic advantage over the last 25 years.

1.11If the basic message from the study for the “high ICT” countries is that they should continue to promote broadband deployment (including the deployment of yet more advanced broadband options) and also pay attention to the complementary factors that help to make broadband a more potent investment, then this message is amplified for the “low ICT” countries.

1.12Clearly such countries can benefit from supply-side policies that promote broadband deployment and competition in the supply of broadband. Such policies can lower the price of broadband and thus encourage broadband adoption, and ICT adoption more generally. However, as Section 4, the case study on Italy and Sweden, makes apparent, such policies might hit a wall in the face of significant constraints on what we term the “demand-side”: the skills of consumers and the willingness of businesses to use technology in economically advantageous ways.

1.13Southern European economies do not seem to have made the transition to being truly “innovation-driven” economies (economies in which innovation, research and development, and technology are the main sources of economic growth). Promotion of broadband networks can be a tool in making this transition, but the effectiveness of this tool depends on efforts that address perhaps more deep-seated structural economic problems.

Non-OECD countries

1.14Non-OECD countries were not a focus of this report, and they were not included in the sample of countries that was utilised for the econometric analysis. The OECD nations that we looked at are relatively homogenous as a group. The United States is significantly more efficient than Portugal or Greece, but the difference between the US and these countries is minor when compared to the difference in productivity and wealth between the US and nations in Africa and South Asia. Thus if our study reaches such guarded conclusions for the OECD region regarding the benefits of broadband, what sort of conclusions would we reach regarding the benefits of broadband to developing nations?

1.15At one level, it would be tempting to conclude that broadband is irrelevant to the needs of such economies. After all, if Internet skills and ICT user skills dampen the economic potential of broadband in a country like Italy, which is relatively rich, they would be an insurmountable problem for countries like India which remain quite poor. Yet we think this would be too pessimistic a conclusion. Clearly the major focus of economic policy in most developing nations should be on improving the quality of basic human and physical capital. However, as India itself shows, there are significant sections of the population that can utilise ICT and even innovate in the ICT arena. These sections of the population might be able to benefit from broadband deployment. Even if “broadband for the masses” remains a far-away goal, it may not be a bad thing to provide good and effective broadband services for those with the potential to use them in economically effective ways.

1.16Further, there may be ways of achieving wider and more effective broadband diffusion. Mobile broadband technologies offer a distinct possibility in this regard. The deployment costs of such technologies may be lower than those of fixed broadband in a developing country environment. Additionally, since a large section of the population in these countries is already accustomed to using a mobile telephone, there may be simple and effective "entry-level" broadband offerings that have low associated costs of adoption and of learning.

Regional policies and "broadband stimulus" packages

1.17A major policy debate around the merits of providing stimulus packages for broadband deployment has emerged in the United States. In this regard, the recommendations that we have made in Connectivity Scorecard 2009, and the recommendations that we are making here regarding the continued importance of investment in complementary capital, appear to finally be gaining recognition in policy-making circles. Professor Yochai Benkler has written of a recent measure:

> *The Senate bill is also the first serious effort to invest in skills training and connecting the availability of physical infrastructure to programs to teach people how to use the systems. An incredibly important, and oft ignored, facet of the problem.*[6]

1.18What we have found for countries logically applies to regions within countries too. Merely adding broadband lines in rural communities and other under-served areas may provide little economic return, or only provide economic returns with a significant lag, until and unless there is adequate attention paid to skills and also to the propensity of business, government and individuals to change their ways of working to take advantage of technology. More traditional communities may be resistant to the kind of disruptive change that broadband and ICT can create. The benefits from adopting a coordinated approach to broadband and ICT would logically seem larger than the benefits from a policy that relies upon the premise "if you build it, they will come."

Conclusions

1.19The results from our study show that broadband — the ultimate melding of the telephone line (or cable television network) with the computer — can have significant payoffs in terms of increasing productivity and economic growth. In countries like the United States, the melding of the telephone and the computer has had a wide-spread economic impact, so much so that it accounts for a significant portion (in excess of 10%) of recent productivity growth. Our model predicts that if the United States had about 5 more broadband lines for every 100 persons (or about 15 million more broadband lines), US GDP would be higher by over $50 billion (or 0.5% of its current level). With 10 more broadband lines per

6 See http://tpmcafe.talkingpointsmemo.com/2009/01/30/broadband_stimulus/.

100 individuals, the productivity benefit would exceed $100 billion. In fact, the leading Northern European nations already have broadband penetration that exceeds the US penetration level by about this amount.

1.20However, our study provides some pause for thought. The finding that the productivity benefits from broadband do not appear in environments where there is a relatively low level of wider ICT diffusion (and ICT-complementing factors such as user skills) supports and amplifies the concern that the issue is not just broadband, but the environment in which broadband is deployed. Such concerns have been mainstream in the academic literature on ICT for many years, and are now becoming mainstream concerns in the policy debate as well.

1.21We hope that this research, based as it is on data pertaining to what is still an early phase of broadband deployment, provides some further insight into the telecoms debate taking place today. In the past, too much policy-making in both the United States and Europe has concentrated on the supply side of the market — that is, attempting to ensure that broadband is available and affordable — without quite realising that the speed of broadband adoption and the uses to which broadband is put are quite contingent on several other factors present in the economy. Failure to adequately recognise the role of the “demand-side” (the skills and habits of the people and businesses that might use broadband) might result in policies that distort markets and weaken the telecommunications industry without achieving much social benefit.

1.22Perhaps the best way to summarise why we remain so confident about the economic impact of broadband comes from the noted economist, Paul Romer:

> *Every generation has underestimated the potential for finding new recipes and ideas. We consistently fail to grasp how many ideas remain to be discovered. Possibilities do not add up. They multiply.*[7]

Structure of the report

1.23The remainder of this report is structured as follows: Section 2 provides a detailed account of the impact of broadband and ICT, and of the existing literature that we have reviewed. Section 3 then discusses our model and the basic results from the model. This is followed by a further discussion of the econometric issues that we considered. Section 4 then moves on to a short case study

7 Paul Romer, as quoted in "Preferences, Promises, and the Politics of Entitlement" (Individual and Social Responsibility: Child Care, Education, Medical Care, and Long-Term Care in America, Victor R. Fuchs (ed.), Chicago: University of Chicago Press, 1995).

comparing Sweden and Italy as examples of countries that simply differ in their ability to utilise technology, illustrating why Sweden is better positioned to take rapid advantage of innovations such as broadband, whereas Italy has a range of fronts on which it needs to improve in order to make the transition to a true innovation-driven economy.

Summary from an economist's perspective

1.24In this report, when we use the term "broadband" we are using it as a short-hand for the spread of networked computing or networked ICT into the wider economy. The effect of broadband that we discuss is a "spill-over" effect, as opposed to a capital deepening effect. In our model, increased broadband investment has two impacts: (a) the capital deepening impact of the investment itself, and (b) a spill-over impact related to the increased diffusion or usage of broadband lines. The model specification is discussed in more detail in Section 3, while Section 2 provides a more detailed literature review.

1.25Our model estimates a production function in first differences. The advantage of doing so is that first differencing removes at least the "spurious correlation" effect that might contaminate estimates of a production function that fail to account for unobserved country-specific variables that influence both the level of productivity and the level of broadband penetration. The estimates that we obtain for the productivity impact of broadband are from a regression of productivity growth against growth in the aggregate non-ICT capital stock, growth in the ICT capital stock, and the change in the level of broadband penetration and voice penetration. The broadband effect is split into two effects: (a) a base broadband effect — the effect of broadband in "low ICT" environments and (b) an additional effect of broadband in "medium and high" ICT environments.[8] The implication of this set-up is that, for a country that has a "low ICT" environment, the effect of *growth in broadband* on *growth in productivity* is given by the coefficient corresponding to (a), whereas the effect in a country that has a "medium ICT" environment or "high ICT" environment is given by the sum of the coefficients corresponding to (a) and (b).

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8 We originally started with three groupings, the low grouping corresponding to the bottom quartile of countries by average PC penetration levels, the medium grouping covering the 25th to the 75th percentile, and the high grouping covering the 75th percentile above. We found that the additional impact of broadband (the impact on top of the "basic" impact of broadband that could be expected in low ICT environments) was about the same in the medium and high groupings, so we collapsed the two groups into one. It should be noted that while we are using the average level of PC penetration as a basis for constructing the groupings of countries, this should not be interpreted as anything other than a relatively crude proxy for general ICT diffusion.

1.26The first effect is statistically insignificant, implying that the effect of broadband in low ICT environments is essentially not different from zero. The second effect is positive and statistically significant, and the sum of the two effects is also statistically significant.

1.27It might be argued that there is still a reverse causality or simultaneity issue at work here, even though the parameter estimates are based on regressions of growth rates against growth rates, rather than levels against levels. Broadband has diffused faster in countries with higher initial levels of productivity (although within this set of countries even the relationship between the initial level of productivity and subsequent diffusion rates of broadband is unclear); but there is no evidence to show that shocks to productivity growth affect broadband. In fact, the evidence suggests that broadband diffusion accelerated in the 2000s, almost everywhere in the OECD, regardless of trends in productivity. The "dot.com bust" might be invoked here, but that seems more like a shock to aggregate productivity *caused* by events in the ICT sector. A regression of the speed of broadband diffusion against the level of initial income and the growth rate of productivity over the years 1998-2007 suggest a strong, positive influence on broadband diffusion of the level of initial income, but a statistically insignificant causal relationship between productivity growth and the speed of broadband diffusion.[9]

1.28We also looked at standard econometric methods for examining the possibility of simultaneity bias in the parameter estimates. Instrumental Variable (IV) techniques similar to those used in Holtz-Eakin (1992) were deployed . The estimates obtained from the IV estimation were not much different from the estimates obtained by Ordinary Least Squares (OLS) estimation, although the variance of the parameter estimates was higher (as expected). Specification tests such as the Durbin-Wu-Hausman and Hausman tests failed to provide a reason for rejecting the OLS estimation. Further discussion of the econometric issues is contained at the end of Section 3.

1.29An interesting aspect of our results is that they appear supportive of the predictions of modern empirical growth theory, *i.e.* that factors — endogenous factors — such as innovative capabilities and the quality of human capital explain a significant amount about why we have not observed a greater level of convergence in income levels or productivity levels within the OECD area. Since

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9 This regression assumes that there is no causal influence of broadband on productivity growth, so that productivity growth is an exogenous variable in the regression.

there is a generally high correlation between income levels and such factors as education levels in the population, spending on research and development, and development of research at the university level, these factors give richer countries some advantages in being able to find what Paul Romer has described as "new recipes" for growth. Broadband and ICT are important new recipes for growth, and the ability of countries to utilise them rapidly provide some of the explanation for why the process of convergence in income levels and productivity levels within the OECD area has come to a halt, or even reversed. Countries in Southern Europe in particular need some new recipes for growth, and there may be a role for strong and pro-active pro-innovation policies in such countries.

2 Economic Impact of Broadband: Existing studies, major issues, results and conclusions

2.1 In this section, we begin by discussing the findings of past studies on ICT generally and broadband in particular, before turning to a description of our model and the major results. We then describe the issues surrounding reverse causality and spurious correlation at a high level, but an in-depth discussion of these issues can be found in Section 3.

Existing literature

2.2 The existing literature on broadband, ICT and telecommunications can be divided into four categories: (a) older literature on the effect of fixed lines telecommunications on economic growth, (b) literature from the late 1990s and early and middle 2000s on the impact of ICT on growth and productivity, (c) "forward-looking" studies, largely from the early and middle 2000s that attempted to project the potential benefits from widespread broadband deployment, and (d) more recent literature attempting to assess the impact of broadband deployment on productivity, output and employment based on the existing experience.

Early literature on telecoms

2.3 The older literature from the 1980s, 1990s and early 2000s, dealt mainly with the impact of fixed line telecommunications on economic growth and productivity. While the early literature on the subject was perhaps simplistic, the studies by Norton (1992) and Röller and Waverman (2001) established a positive and statistically significant relationship between telecoms penetration and economic output.

2.4The study by Röller and Waverman in particular controlled carefully for the problems of spurious correlation and reverse causality, but still found very high impacts of fixed-line telecommunications deployment on economic growth in the OECD area. This study concluded that perhaps 1/3rd of economic growth in the OECD between 1970 and 1990 was attributable to the growth in fixed-line telecommunications network. Such very high impacts may be plausible in light of the fact that there are several positive indirect benefits that other sectors can reap as a result of an expansion of telecom networks. These might be termed “spill-over” benefits. Strong micro-economic evidence for the existence of such spill-over benefits was found in the study by Greenstein and Spiller (1996).

2.5Such spill-over benefits likely arise because having a well-developed telecommunications network lowers transaction costs and makes it possible to do business over long distances without the need for travel or utilising older and slower modes of communications such as post. Over time, the simple voice telephone network has been augmented by such developments as digitalisation, the advent of ISDN, DSL and cable broadband and telephony services, and mobile telephony. These developments have greatly multiplied the ability of telecommunications network to be used for transmitting information, almost instantaneously, between remote users. In particular, the last 20 to 25 years have seen the widespread diffusion of computers and the computerisation of much information. However, such information was not necessarily “networked” (except within a local area such as a company).

2.6For example, a government department may have had computerised records on various matters of interest to the public and to corporations, but accessing such information might have required either travel, or for such information to be transferred to a “floppy” disk and sent out via mail. Today, such information can be made instantaneously available to anyone with a broadband or Internet connection, anywhere in the world, via a website. Often such websites allow for a far higher degree of interactivity and specificity in transactions than was conceivable as recently as 15 years ago. Thus the developments of the last 15 years have seen the development of the “networked” computer, with electronic information available to a vast number of users, regardless of geography, and often for free.

2.7Despite the proliferation of computers in the 1980s and 1990s, there was precious little evidence that the new technology had any impact in improving productivity. For example, productivity growth in most Western countries had slowed down significantly after 1973 (as compared to the period from 1945-73). There seemed to be an evident paradox, which became known as the "Solow Paradox" after the Nobel laureate economist, Robert Solow, who famously stated that the impact of computers was being felt everywhere except in the productivity statistics.[10]

The literature on ICT

2.8However, starting from about the late 1990s, a series of U.S. studies started to find significant impacts of ICT on business productivity. While these studies concentrated on ICT generally and not on telecoms or the Internet, their results are highly relevant to the current debate on the impact of broadband.

2.9The apparent resolution of the Solow Paradox may have been related to the availability of better data, and to the passage of time. As Crandall, Litan and Lehr (2007) describe matters, ICT (such as computers and telecoms) is becoming a General Purpose Technology (GPT) which is used widely across the economy. It fundamentally transforms the way in which firms do business with each other and with their customers; in many cases, it fundamentally transforms the way that firms produce things. Thus the effects of ICT may have been properly observed only after a considerable lag. In particular, it may have taken firms and individuals some time before they were able to learn how to use ICT effectively, and thus the effectiveness with which individuals, firms and governments learned to utilise ICT increased over time.

2.10By the early 2000s, US aggregate data was beginning to reflect the benefits of ICT substantially. Oliner and Sichel (2000) suggested that perhaps 56 percent of the growth in labour productivity could be attributed to ICT. Jorgenson, Ho and Stiroh (2007) estimated that ICT accounted for nearly 60 percent of the growth in US labour productivity between 1995 and 2001, although they also estimated that the ICT effect had slowed between 2001 and 2005. Most of these studies used

[10] "We'd better watch out," *New York Times* (July 12 1987) Book Review, 36.

growth accounting methods, rather than econometric techniques, and did not address issues of causality versus correlation as such.[11]

2.11Puzzlingly, European (and Canadian) data failed to show the same positive effect of ICT. In the middle 2000s, several papers addressed the differences between Europe and the United States. Many of these papers found that the main difference between Europe and the United States appeared to be that the benefits of ICT had not been felt to the same extent in Europe in sectors that were heavy users of ICT, such as retail and finance. It was speculated that some of this apparent European shortfall in the “ICT-using” sectors of the economy might be linked to European firms’ not being able or willing to undergo significant transformations (including reductions in workforce and changes in work routine) that might be enabled by ICT.

2.12However, even the United Kingdom and Canada, whose economies were relatively more flexible compared to Continental European economies, failed to show the same extent of ICT-led productivity acceleration as the United States. Basu et al. (2003) pointed out that even though ICT investment had boomed in the United Kingdom in the 1990s, the country had failed to see the same spill-over benefits (measured through total factor productivity) as the United States. They suggested that some of this gap might be attributable to the fact that UK firms had taken some time to invest in “complementary capital” (worker capital, organisational transformation) and thus there was some evidence that the UK would see a similar magnitude of ICT spill-over as the US had, albeit with a delay.

2.13Using an econometric framework very similar to what is used in this report and the one employed by Röller and Waverman, Waverman and Fuss (2005) attributed just over half of the difference in Canadian and US labour productivity (GDP per hour worked) to what they termed either ICT capital deepening (per hour worked, Canadian workers had significantly less ICT capital than American workers) or ICT “spill-over” effects. These last effects were captured through the

[11] Growth accounting techniques decompose economic growth into three main components: (a) growth that arises because of an increase in the amount of labour supplied or hours worked, (b) growth that arises because of increases in capital (workers have more capital to work with), and (c) so-called “total factor productivity”, which reflects the increased efficiency with which labour and capital are utilised. More sophisticated growth accounting techniques can be used to separate out the effects of different types of capital (e.g., ICT capital such as computers versus non-ICT capital such as machinery), or the quality of labour supplied. However, growth accounting techniques suffer from a number of limitations: for example, they assume constant returns to scale and also assume that the marginal productivity of different types of capital is similar; econometric modelling allows one to test these assumptions.

diffusion of ICT assets such as telecoms and personal computers in the Canadian economy.

Lessons from the ICT literature

2.14Overall, however, the literature on ICT, in particular the literature dealing with cross-country comparisons of the effects of ICT, suggested strongly that the impact of ICT investment was contingent on the context in which such investment was deployed. The basic findings from the literature seemed to be:

- The significance of ICT was that virtually all sectors of the economy were able to use it for their economic benefit. The effects of ICT would eventually be felt across the entire economy;
- However, it would take firms and individuals some time to figure out how to best use the ICT available to them. In some cases, firms, individuals and governments would have to make investments in "complementary capital" (worker training and skills, organisational routines) to recognise the full benefits of the technology;
- Thus the full effect of ICT might be recognised with something of a lag, and might be amplified by the flexibility and willingness of the users of ICT to transform their work habits and update their skills. Even at the level of individual firms rather than aggregate economies, studies such as Haskel, Criscuolo and Crespi (2007), found that the impact of ICT was fully realised only when investment in ICT was accompanied by organisational change.

2.15As subsequently discussed, these findings of the ICT literature are highly relevant to the findings of this report as regards broadband.

"Forward-looking studies" of Broadband

2.16As broadband deployment began in earnest in the late 1990s and early 2000s, it sparked some interest into the potential economic effect of this network deployment. Studies such as Crandall and Jackson (2001) and Crandall, Jackson and Singer (2003) highlighted the potential economic impact of broadband. The conclusion from these studies was that (in terms of net present value) the additional economic output generated as a result of broadband deployment and its effect on the wider economy would be several hundred billion dollars, and the creation of hundreds of thousands of new jobs. Most of these studies used plausible assumptions about the rate at which broadband would diffuse through the aggregate economy, and married these assumptions to other relevant economic information — for instance, the likely elasticity of demand and prices for broadband service, or the economy-wide “multiplier” effect of a dollar invested in a telecommunications network.

2.17Varian et al. (2002) looked at firm level data for the US, UK, Germany and France to estimate the impact of the Internet on cost savings and the productivity growth rate. They found that Internet business solutions were being adopted by organisations across all industries and that this accounted for a significant proportion of projected productivity growth. Those deploying Internet business solutions had realised cumulative cost saving of $163.5 billion in the US, UK, France and Germany, with most of those savings coming after 1998. Once all Internet business solutions were fully implemented (by 2010), US organisations were expected to realise over $500 billion in cost savings, and organisations in the UK, Germany and France over €88 billion. Almost half of the projected *increase* in US productivity *growth* between 2001 and 2011 could be accounted for by firms adopting Internet business solutions, while Internet business solutions could account for more than one third of the projected productivity growth increase in the UK, Germany and France.

Econometric studies of the impact of broadband deployment

2.18Since broadband is a relatively recent technology, there are relatively few econometric studies regarding the impact of broadband deployment, particularly not at the level of the aggregate economy.

2.19Some recent studies from the United States look at the impact of broadband on output and employment at the state level. Crandall, Litan and Lehr (2007) do a detailed analysis of the impact of broadband on economic output at the level of individual American states, and on employment at the level of individual industries. They fail to find a positive and significant relationship between output and broadband deployment, but they find strong evidence of broadband usage driving increases in employment in sectors that are likely to be ICT-using (finance, education and healthcare). They find some statistically significant evidence that broadband has increased output in some sectors, chiefly service sectors. Some other studies (notably Lehr et al. (2006)) find a positive effect on employment and rental prices in local communities where broadband was available.

2.20Thompson Jr and Garbacz (2008) appear to find an even more ambiguous, and counter-intuitive, relationship between broadband deployment and output at the level of individual states. Their econometric analysis finds that there is a negative and statistically significant relationship between broadband deployment and state output. Although they raise the possibility that broadband has a "water-cooler" or time-wasting effect on workers' productivity, they do not stress this possibility, as it seems rather counter-intuitive and difficult to support with any evidence. As an example, without ready access to information over the Internet, including other academic studies, journal articles, and the like, and the ability to communicate easily and share data instantaneously with colleagues in other parts of the world, our study would have been far more time-consuming and far more costly a mere 10 years ago. It is hard to see how these very substantial effects could be outweighed by some additional time spent "surfing" the Internet.

2.21Intriguingly, the same authors (2007) find that in the context of a stochastic frontier analysis, which they conducted for a group of OECD countries, Internet usage appears to decrease economic efficiency. Again the result is quite counter-intuitive.

2.22Koutroumpis (2008) utilises the framework developed by Röller and Waverman and estimates that broadband deployment has had a strong and statistically significant effect on economic growth in the European Union, although the data covers only the years 2003-2006. He finds that the growth effect of broadband is more pronounced in countries with high existing levels of broadband penetration — that is, the marginal impact of adding broadband lines is higher in countries where there is a "critical mass" of broadband lines already in place than in countries where broadband deployment is low. This finding recalls the finding of "critical mass" effects by Röller and Waverman in respect to fixed-line telecommunications networks.

Our modelling framework: an overview

2.23In this report, we utilise an augmented production function approach, which is derived from earlier work (Waverman and Fuss, 2005). There are, however, some significant departures between the principal methodology that we utilise for this work and the methodology that we (and others) have utilised in past studies.

2.24These differences centre around the need to control for the two factors, simultaneity or "reverse causality", and spurious correlation, that we mentioned at the outset of this section.

2.25If our goal is to estimate a relationship between a variable such as GDP and another variable such as broadband penetration or telecom penetration, one must control for a number of other factors that also influence the level of GDP. For example, there may be a number of factors such as the quality of institutions, rule of law, regulatory environment and attitude of citizens to technology that may happen to promote growth and also promote higher levels of telecom or broadband penetration. Failure to control for the influence of these factors in the econometric model may produce biased estimates, or a "spurious" relationship between GDP and broadband penetration.[12]

2.26The issue of reverse causation is also a significant one. Telecoms or broadband may help to make a country richer, but it is also true that richer countries tend to have higher penetration and usage levels of such technologies. To some extent, the positive and bi-directional relationship between telecoms and wealth is the result of various growth-promoting factors that also influence telecoms in the same direction (as described in the previous paragraph); however, there may also be significant "income effects" associated with telecoms — as individuals and nations become richer (regardless of all the other factors one considers) they will tend to buy more telecoms-related services.

2.27These issues acquired prominence in the economic literature in the early 1990s, when there was a significant debate about the impact of public infrastructure such as roads and highways on economic output. Most notably, Aschaeur (1989) presented results that showed an extremely strong and statistically significant impact of public infrastructure on economic output at the level of individual states. Aschaeur's study suggested that declining U.S. productivity growth was attributable mainly to the reduction in investment in public infrastructure such as roads and highways.

2.28However, a number of studies in the early 1990s showed that the very high effects of public infrastructure estimated by Aschaeur vanished when appropriate econometric controls were introduced into his model. Specifically, several studies introduced "state-level fixed effects" (a way of controlling for the unobserved characteristics of a state that are more or less fixed over the time period observed — e.g., effects related to size, culture, institutional factors, and the like) into the analysis, and found that once these fixed effects were accounted for, the very large estimated returns to public infrastructure simply disappeared. Examples of such work include Holtz-Eakin (1994) and McGuire and Garcia-Milà

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[12] It should be noted that when referring to spurious correlation in this report we are using it in a sense similar to Röller and Waverman (2001), as opposed to the term "spurious regression" which is used in time-series econometric analysis.

(1992). Thus these studies showed that the earlier literature on very high returns to public infrastructure was flawed when spurious correlation and simultaneity were appropriately accounted for.

2.29Röller and Waverman established a model where they controlled for not just the spurious correlation problem described above, but also provided a structural framework for controlling for reverse causality. They did this by estimating not just an equation that looks at the relationship between GDP and various other attributes including telecoms penetration, but supply, demand and investment equations which control for the reverse relationship between income (GDP per capita) and telecommunications penetration.

2.30In a different context — that of quantifying the effects of "ICT spill-over" — Waverman and Fuss (2005, 2006) used a similar multi-equation approach, extending the Röller-Waverman model significantly.

2.31The current approach borrows heavily from the spirit of the Waverman-Fuss paper, but departs significantly from it in one key respect. Here we do not utilise a multi-equation model but rather utilise other techniques (first-differencing and instrumental variables) to (a) control for and (b) test for, the spurious correlation and simultaneity bias problems.

2.32The main reason for this departure from the previous approaches is that there are a number of practical data-related issues which make it difficult to analyse the determinants of supply, demand and investment for broadband in quite the same way that Röller and Waverman were able to do for fixed-line telecommunications. Their study covered the period 1970-1990, when the market structure of the telecommunications industry in most of the OECD was rather simple: state-owned or quasi-public firms that provided a relatively homogenous telephone service product. Thus, in their model, the (relatively) readily available data on total telecommunications investment could safely be used in a regression analysis where it could be correlated to the growth in fixed line subscriptions.

2.33However, one cannot explain the evolution of telecommunications investment through broadband alone, as there are other aspects of the industry that are actively consuming investment — for example, mobile investment, or continued investment in upgrading and maintaining fixed line networks. Further, there is little systematic data available on a cross-country basis pertaining to broadband investment (as distinct from all other telecoms or fixed-line investment) alone, and the data on mobile network investment (much of it made by private operators) are also erratic. Röller and Waverman were able to use the average revenue per telephone subscriber as a proxy for price in their demand and supply equations. However, if one had a separate equation explaining broadband penetration alone, the best source of plausible price data would be OECD data covering the last few years only.

2.34Further one would face the difficulty that either one would have to confine the analysis to only the years in which broadband prices and penetration rates were available, or to find some way in which the non-availability of broadband for reasons unrelated to market structure, prices or GDP, could be handled in the context of an overall demand function for telecommunications.

2.35Our motivation, however, is best explained by the fact that we want to estimate the impact of broadband over and above that of existing communications technologies, such as voice networks, and in the context of ICT-complementing investments. In addition, aggregate productivity or output , within the production function framework, depends on other factors such as the amount of ICT and non-ICT capital in the economy. Obtaining economically sensible parameter estimates for these is a difficult task if one were only going to utilise a few years worth of data. Growth and productivity are inherently long-term phenomena, and the goal here is to estimate the contribution to economic growth and productivity of the recent addition of broadband to the list of ICT technologies, taking into account that other capital assets and other ICT technologies have been around for many years before broadband was introduced.

2.36We do estimate annual production function data for the period 1980-2007, although for much of this period broadband was unavailable. However, this yields more economically sensible estimates of the other relationships that are of relevance to us: the relationship between productivity and growth in ICT and non-ICT capital stocks, and the relationship between other telecom assets and productivity.[13]

2.37Thus it is difficult to implement the full multi-equation framework that Röller and Waverman used. The main contribution of the multi-equation framework is to

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13 As we eventually utilise first-differenced data, but do not utilise a dynamic regression model, our eventual model is an equilibrium explanation of productivity growth.

tackle the simultaneity or reverse causality bias. However, if the remaining equations cannot be specified correctly or is not using truly sensible data, then they may not achieve this goal, but may instead complicate the overall estimation procedure.[14]

2.38We explain our model and discuss the data that we used in the following section.

3The model

3.1At the root of our model is a "characteristics-based" production function framework. In this framework, output (y) can be expressed as a function of capital (ICT and non-ICT) inputs, as well as "characteristics" of the ICT capital stock, which could include voice penetration, PC penetration, and broadband penetration. These characteristics could be potentially endogenous — for instance, they would be in the instance of reverse causality between output and the characteristics. The characteristics are best seen as representing the diffusion of various forms of ICT capital in the wider economy.

3.2This production function can be written as follows:

$$Y = AH^{al} KAP_{NI}^{aNI} \left[G\left(KAP_{ICT}, X\right)\right]^{aIT} e^{at*t} \qquad (1)$$

where Y is aggregate output (measured by real GDP), H is the labour input (measured by the total hours worked), and KAP_{NI} is the country's real capital stock net of the ICT capital stock. X is a vector of characteristics of the ICT capital stock. The term "t" represents a time trend, which is a proxy for autonomous technical change. Autonomous technical change represents technology shocks that are not captured by the model, or other factors such as smoothly changing worker skills levels.

3.3G(.) is a hedonic function of the ICT capital stock and its characteristics, which we assume takes the following form:

14 There were some similar issues encountered in the Waverman-Fuss analysis, for example, the fact that mobile telecommunications had only been available for a small amount of the total period that was analysed. In this case, mobile penetration was essentially added to fixed-line penetration for the period in which it was available, and price and income elasticity for mobiles could be estimated by use of dummy variables. A similar approach could be deployed for broadband if broadband penetration were added to total telecom penetration, but since the major focus is to estimate the relationship between broadband and output or productivity, this approach is less attractive in the present instance.

$$\log G = \log KAP_{ICT} + B_{PEN} PEN + (B_{BROADBAND} + B_{MEDHIGH} * MEDHIGH) * (BRPEN) \quad (2)$$

Here, KAP_{ICT} refers to the ICT capital stock,[15] PEN is the penetration rate (lines per 100 population) of voice telecommunications (fixed and mobile)[16], BRPEN is the penetration rate (lines per 100 population) of broadband (cable and DSL), and MEDHIGH is a dummy variable that assumes the value 1 when the average penetration rate of PCs[17] for a country puts it in the top 2/3rds of the sample, and 0 otherwise.[18] Thus the effect of broadband penetration in these countries is given by the sum of the coefficients ($B_{BROADBAND} + B_{MEDHIGH}$). In this way, we account for the fact that the impact of broadband may be contingent on the diffusion of other ICT assets (especially computing assets) in the economy. Higher average diffusion of these other ICT assets is also likely to indicate a higher level of investment in so-called complementary capital, which may be quite important in helping to realise the benefits of broadband. In this way, we were able to test whether or not (a) there were measurable productivity benefits from broadband diffusion, and (b) whether these benefits were everywhere equal.

3.4This aggregate production function is then transformed into a model of productivity or GDP per hour worked, by taking (natural) logarithms of the variables and subtracting the log of hours worked from both sides of the equation. The reduced form equation for labour productivity that we estimate is as follows (note the subscript i is used to index countries, and t is used to index time or years):

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15 The ICT capital stock is composed of three principal asset types: communications equipment assets, IT equipment assets and software. Higher investment in broadband involves purchases of significant amounts of computing equipment, central office electronics, fibre-optical cables, etc, although some investment is in structures (ducts).

16 Note: the mobile penetration rate climbs very rapidly in several countries, particularly in Europe. However, the usage level (as measured by subscriber minutes per month) for mobiles is far lower than for fixed-lines, especially in the early years. The heavier volume of calls and minutes per fixed line was particularly pronounced in the first half of the 1999-2007 time period, and is likely to be particularly pronounced for business communications. Thus we take account of the lower usage levels of mobile to calculate an adjusted mobile penetration, which we then add to the fixed penetration rate to get a "total voice penetration rate." The regression results are not much affected by this transformation.

17 The time period over which this average is calculated proves not to be relevant. Thus one can use the average level of PCs per 100 population for 1980-2007 or just 1998-2007 to group countries into the bottom third and the top two-thirds respectively, without changing the countries that fall into the two groups.

18 Interestingly, there is a near-perfect correlation between average PC penetration rates over 1998-2007, or even 1980-2007, and ranking on Connectivity Scorecard 2009. Thus the country groupings are identical to the groupings obtained if the Connectivity Scorecard rankings were used as the basis for groupings instead.

$$\log(GDP_{it}) - \log(H_{it}) = a_0 + a_t t + a_k[\log(KAP_{NICT}) - \log(H_{it})] + a_{ICT}[\log(KAP_{ICT,it}) - \log(H_{it})] + (a_k + a_l + a_{ICT} - 1)\log(H_{it}) + a_{PEN}(PEN_{it}) + (a_{BRPEN} + a_{MEDHIGH}(MEDHIGH)) \times (BRPEN) + u_{it} \quad (3)$$

3.5The term u_{it} is a disturbance term in the equation. The coefficient on $\log(H_{it})$ can be seen as a measure of the returns to scale exhibited by the production function, with a zero value being equivalent to constant returns to scale.

3.6A major issue that has been raised by the empirical literature on estimating aggregate production functions across regions is whether or not the appropriate specification of the production function should feature an intercept term a_0 that is constant across countries, or whether one should use a fixed-effects specification, where the productivity equation for country *i* at time *t* is given by:

$$\log(GDP_{it}) - \log(H_{it}) = a_i + a_t t + a_k[\log(KAP - \log(H_{it}))] + a_{ICT}[\log(KAP_{ICT,it}) - \log(H_{it})] + (a_k + a_l + a_{ICT} - 1)\log(H_{it}) + a_{PEN}(PEN_{it}) + (a_{BRPEN} + a_{MEDHIGH}(MEDHIGH)) \times (BRPEN) + u_{it} \quad (4)$$

3.7Here the intercept term is allowed to vary by country, effectively resulting in a mean-differenced regression. Use of fixed effects is particularly important where the fixed effects are picking up on some attributes that are related to country size, but is perhaps less relevant in a model where the dependent variable is productivity and not the level of output. In any case, we ultimately estimate the model in first differences, which results in the differencing out of any country fixed-effects.

3.8We estimate the model above in first differences for a sample of 15 countries, covering the period 1980-2007. It should be noted that the intercept term is differenced out, and the coefficient obtained on the constant term[19] in the first-differenced regression model is the coefficient on the time trend, which is an indication of autonomous technical change. The consequence of the first-differencing is that the productivity model is effectively an equilibrium explanation of productivity growth, with no dynamic component.

[19] Another point worth making here is that since membership in the “MEDHIGH” group is fixed (i.e., countries do not jump from one group to another over time), the dummy variable setup is not affected by the differencing.

3.9The rationale behind using the differenced model is discussed in the sub-section on the estimation results. Before that, however, we turn to a discussion of the data that we used for our estimation.

Data used

3.10Our sample consists of 15 Countries: 14 European countries, and the United States, covering the years 1980-2007. The principal dependent variables used in the regressions and the sources from which they were derived are described in Table 4 below.

Table 4: Principal variables

Variable	Description	Data Source
Productivity growth rate	Difference in log (GDP/Hour)	The Conference Board, Total Economy Database, 2008.
Non-ICT capital stock growth rate	Difference in log (non-ICT capital/ Hour)	Marcel P. Timmer, Gerard Ypma and Bart van Ark (2003), IT in the European Union: Driving Productivity Divergence?, Research Memorandum GD-67 (October 2003), University of Groningen, Appendix Tables, updated June 2005.
ICT capital stock growth rate	Difference in log (ICT capital/ Hour)	Marcel P. Timmer, Gerard Ypma and Bart van Ark (2003), IT in the European Union: Driving Productivity Divergence?, Research Memorandum GD-67 (October 2003), University of Groningen, Appendix Tables, updated June 2005.
Change in Voice penetration	Change in number of voice lines (fixed and mobile) per 100 population	ITU, World Telecommunication/ICT Indicators Database, 2008.
Change in Broadband penetration	Change in number of broadband lines (cable and dell) per 100 population	ITU, World Telecommunication/ICT Indicators Database, 2008.
PC penetration	Number of PCs per 100 population	ITU, World Telecommunication/ICT Indicators Database, 2008.

3.11Of considerable importance in this estimation exercise, data on capital stocks were obtained from the Groningen Growth and Development Centre (GGDC). A detailed description of the methodology used to construct these capital stocks can be found on their website at www.ggdc.net. The GGDC capital stock measures make use of the OECD's "price index harmonisation" proposed by Schreyer (2002). This harmonisation method uses the US "constant-quality" price indices for IT and Communications equipment as the starting point and then accounts for country-specific inflationary factors — for example, the authors apply the ratio of the US IT price index to the US GDP deflator to control for IT inflation relative to general inflation, and then apply this ratio to the particular country's GDP deflator index to obtain the country-specific IT goods deflator. In other cases, they apply the US ratio of IT to non-IT capital good price deflators to the country-specific non-IT capital goods price index (where available). Such an approach seems intuitively appealing, since IT goods are widely traded with most countries being net importers of IT equipment; therefore, the rapid declines in constant-quality prices of computers, semiconductors and the like reported by the US are also being experienced in other advanced economies.

3.12In our analysis, we constructed Tornqvist quantity indices for the ICT capital stock instead of using simple linear aggregations across the three major asset classes: Communications Equipment, IT equipment, and Software. The construction of such quantity indices is preferable to using simple linear aggregations of the capital stock, since it is less affected by the problems of rapid deflation that characterise ICT capital goods. The GGDC's capital stock estimates only extend to 2004. However, we have estimated reasonable growth rates for capital stocks and capital services for the period 2005-07, and used these to extend the capital stock data for the last 3 years.[20]

3.13Data on GDP per hour worked and total hours worked were obtained from the Conference Board's Total Economy Database 2008. The data on capital stocks and GDP were (respectively) in 2000 local currency and 1990 US$ (using "Geary-Khamis" exchange rates). All monetary variables were ultimately converted into 2000 US$ at purchasing power exchange rates.

Telecommunications and ICT Data

3.14Data on telecommunications penetration and broadband penetration rates were obtained from the ITU's World Telecommunications Indicators 2008 dataset, as were data on personal computer penetration.

Summary statistics and descriptions of data

3.15Summary statistics for some of the regression variables for 1980-1997 are provided below in Table 5.

[20] More details of how we extended the capital stock series for 2005-07 can be obtained from the authors.

Table 5: Average growth rates for regression variables, 1980-1997

	Productivity	Non-ICT capital stock	ICT capital stock	Adjusted Voice penetration
Mean	2.15%	2.36%	13.56%	1.61
Standard deviation	1.95%	2.45%	5.76%	1.05

3.16Table 6 provides annual growth rates or percentage point changes in penetration rates for the variables (including broadband penetration) for 1998-2007.

Table 6: Average growth rates for regression variables, 1998-2007

Year	Productivity	Non-ICT capital stock	ICT capital stock	Broadband penetration	Adjusted Voice penetration
1998	1.50%	0.32%	18.67%	0.00	4.96
1999	1.66%	0.50%	19.75%	0.20	5.94
2000	2.78%	1.25%	18.23%	0.51	7.50
2001	0.96%	1.44%	14.77%	1.46	2.67
2002	2.09%	2.78%	11.14%	1.99	1.51
2003	1.61%	2.12%	7.06%	2.66	0.75
2004	2.22%	1.46%	5.79%	3.74	1.30
2005	1.14%	0.96%	5.43%	4.28	1.73
2006	1.44%	0.46%	4.55%	4.20	1.43
2007	1.18%	0.58%	3.81%	3.54	0.44
Total	**1.66%**	**1.19%**	**10.92%**	**2.15**	**2.92**

3.17Average PC penetration rates for each country for the period 1998-2007 are shown together with broadband penetration rates in Table 7 (these are penetration rates in levels).

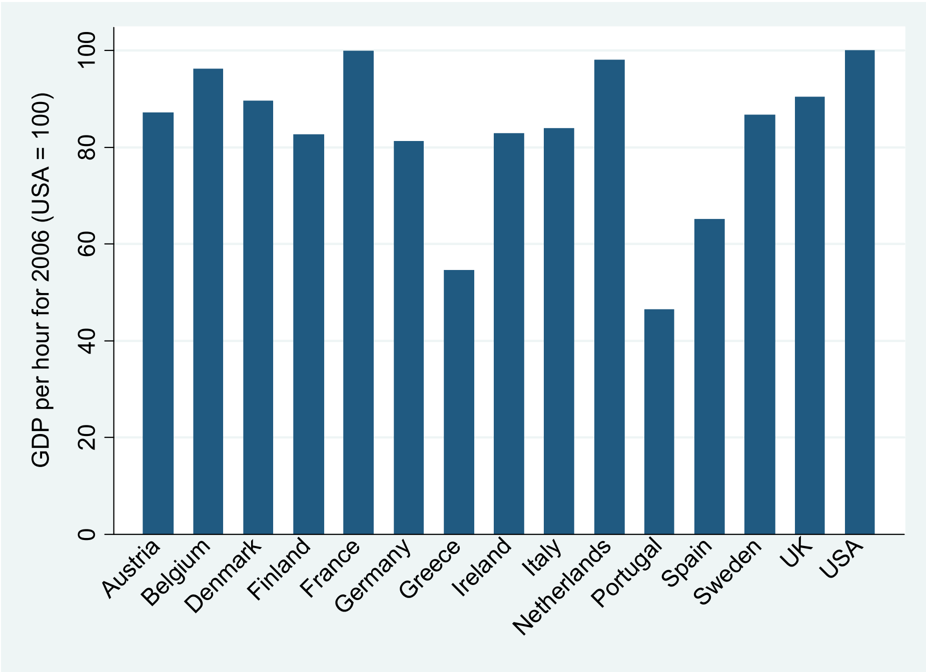
Table 7: Average PC and broadband penetration rates, 1998-2007

Country	Average PC penetration	Average broadband penetration
Austria	44.14	6.62
Belgium	29.16	9.22
Denmark	57.16	10.59
Finland	42.67	11.19
France	40.34	6.40
Germany	44.57	7.54
Greece	7.81	0.70
Ireland	42.59	2.56
Italy	23.06	4.28
Netherlands	54.82	13.45
Portugal	12.48	4.54

Spain	21.51	4.88
Sweden	63.35	7.86
UK	47.75	6.29
USA	65.26	7.51
Total	**39.78**	**6.99**

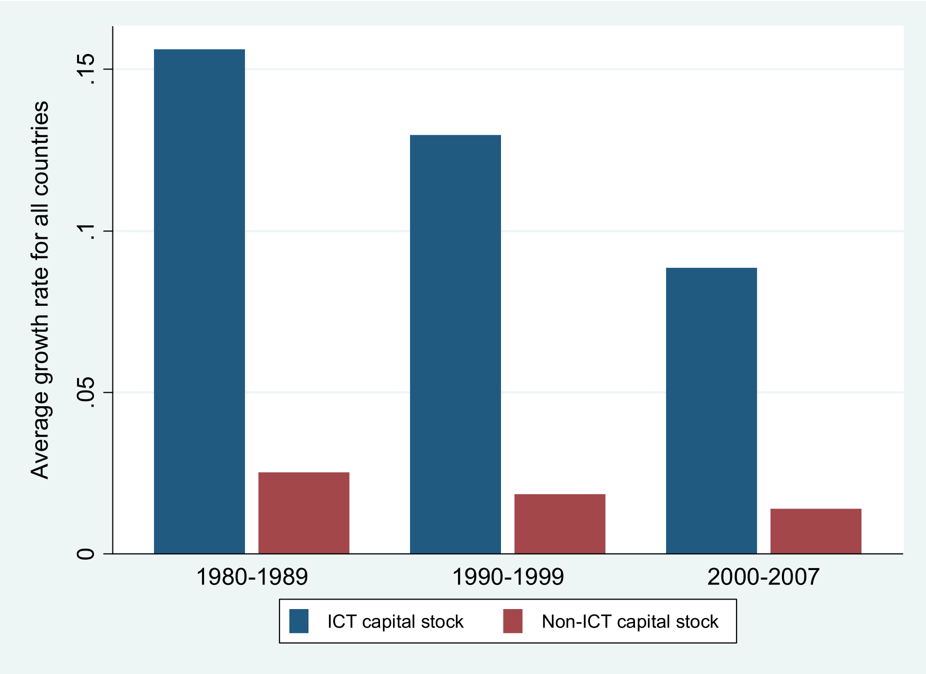
3.18Figure 1 shows the 2006 level of GDP per hour worked, relative to the US level. By the end of 2006, the US had overtaken Belgium and France to have the highest level of worker productivity in the sample.

Figure 1: Level of GDP per hour worked, 2006 (USA = 100)



3.19Figure 2 shows the relative growth rates of ICT and non-ICT capital stock, analysed over three periods.

Figure 2: Relative growth rates of ICT and non-ICT capital stock



3.20It can be readily seen from the data that there is significant variation in productivity levels, and broadband and PC penetration rates, across the sample of 15 countries. However, trends in the growth rate of ICT capital stock seem to show less variation, with most countries recording rather high growth rates for ICT capital for the entire time period. The GGDC's database provides calculations for the growth rate of ICT and non-ICT capital services, which can be used to confirm the trends we report here.[21]

Estimation results

3.21The aggregate productivity model was estimated in first differences. The first-differencing approach appears to tackle two problems that would be encountered in a simple OLS model in levels: (a) it differences out country-specific time-invariant heterogeneities that probably play a significant role in generating spurious correlation, and (b) it tackles potential issues of "non-stationarity" that might not be addressed by simply inserting a time trend into a model in levels.

[21] The data rather suggest that the growth rate of ICT capital services was especially rapid in the 1980s and 1990s, and has slowed somewhat since then. However within each of these periods, the capital services growth rate for ICT assets is relatively stable and almost always quite high. Thus the growth rate of ICT capital services seems not to be particularly driven by country-specific or year-specific factors.

3.22In addition, there is some reason to believe that the simultaneity issues raised by Röller and Waverman would be less significant when one is performing a regression in growth rates (or differences) than in a model in levels. Broadband has generally diffused faster in countries that have high levels of GDP per capita or productivity to begin with than in countries with relatively levels low income per capita . But these are not always the countries that have experienced the fastest rates of productivity growth or output growth. For example, broadband has diffused rapidly in Denmark, which is a country that had high per capita income and worker productivity to begin with, but where the *growth rate* of productivity in recent years has been rather low.

3.23The first-differenced parameter estimates are shown below (Table 8). Because of a surprising level of high and negative correlation between the growth rate of the "hours worked" variable and the growth rate of some other variables, the model is first estimated under the assumption that there are constant returns to scale and thus that the coefficient on hours worked is zero. Subsequently, we tested the sensitivity of the results to various assumptions on the "returns to scale" parameter (the coefficient on hours worked), and found that the remaining parameter estimates were not much affected by the assumption. This was done by allowing the "returns to scale parameter" to vary in a range between 1.00 and 1.20, and examining the impact on the remaining parameter estimates.

3.24Table 8 shows the results from the regression run over the entire period from 1980-2007. Table 9 shows the results from the regression run over just the "restricted" period from 1998-2007, the period in which broadband deployment has occurred. The main differences between the two sets of estimates are that the voice penetration coefficient and the coefficient on autonomous technical change (the constant term) are estimated very imprecisely with the restricted data set. Since first-differencing induces serial correlation in the error terms, the reported standard errors are Newey-West standard errors. A test for the significance of the sum of the two broadband effects shows that this sum is statistically significant at about the 94 percent level of confidence.

3.25The coefficients on ICT capital and non-ICT capital also rise for the restricted regression, and the coefficient on ICT capital increases relative to the coefficient on non-ICT capital. However, since the ratio of ICT capital to non-ICT capital is far higher in 1998-2007 than in 1980-2007, it makes sense for the ratio of the regression coefficients to also be higher, and does not imply insensible estimates of the marginal product of ICT capital.

Table 8: Initial OLS parameter estimates (all regressions estimated in first-difference form)

		Coefficient	Standard error	t-stat	P>t
Non-ICT capital stock		0.3759	0.0529	7.10	0.000
ICT capital stock		0.0526	0.0212	2.48	0.014
Broadband penetration	BASE	-0.0016	0.0012	-1.39	0.165
	MEDHIGH	0.0027	0.0010	2.67	0.008
Voice penetration		0.0007	0.0003	1.93	0.055
Constant		0.0040	0.0036	1.14	0.256

Note: The p–value is 0.06 for the F-test, with the null hypothesis being that the sum of the two broadband effects is zero, showing that the sum of the two effects is estimated with reasonable precision. Reported standard errors are Newey-West standard errors, correcting for AR(1) correlation in the residuals. Reported R-squared is 0.30, with Root MSE of 0.0151. N=382.

Table 9: Initial OLS parameter estimates, 1998-2007 data only

		Coefficient	Standard error	t-stat	P>t
Non-ICT capital stock		0.4462	0.0826	5.40	0.000
ICT capital stock		0.0662	0.0253	2.62	0.010
Broadband penetration	BASE	-0.0010	0.0014	-0.73	0.465
	MEDHIGH	0.0024	0.0010	2.34	0.021
Voice penetration		0.0001	0.0004	0.34	0.735
Constant		0.0018	0.0050	0.36	0.721

Note: F-test yields p-value of 0.09 against the null that the sum of the two effects is zero. Reported R-squared of 0.3694, Root MSE of 0.01191, N=136.

3.26 Overall, the parameter estimates seem sensible and in line with the predictions of economic theory. The effect of broadband is shown to be positive and significant for the "medium and high ICT" groups. However, the negative sign of the "low" or "base" broadband penetration coefficient is a puzzle. Since this is not statistically significant, and there is no economically sensible reason to believe that this coefficient actually could be negative, we next run the regressions for the two time periods (Tables 10 and 11), constraining this coefficient to be zero. This generally improves the precision of the remaining parameter estimates. The broadband effect in the "medium and high" countries actually increases (especially when we use the shorter time-period of 1998-2007, which affects the coefficient estimates on voice penetration and the autonomous technical change term).[22]

Table 10: Constrained OLS estimates[23]

		Coefficient	Standard error	t-stat	P>t
Non-ICT capital stock		0.3774	0.0524	7.20	0.000
ICT capital stock		0.0584	0.0196	2.98	0.003
Broadband penetration	BASE	0			
	MEDHIGH	0.0013	0.0006	2.28	0.023
Voice penetration		0.0006	0.0004	1.80	0.073
Constant		0.0030	0.0032	0.94	0.350

N=382; R-squared=0.30, Root MSE= 0.01516.

Table 11: Constrained OLS estimates, 1998-2007 data only

		Coefficient	Standard error	t-stat	P>t
Non-ICT capital stock		0.4462	0.0837	5.33	0.000
ICT capital stock		0.0765	0.0183	4.17	0.000
Broadband penetration	BASE	0			
	MEDHIGH	0.0018	0.0006	3.01	0.003
Voice penetration		0.0002	0.0004	0.41	0.680
Constant		-0.0007	0.0032	-0.21	0.837

N=136; R-squared = 0.37, Root MSE = 0.1189.

Implications of results

3.27On average, US worker productivity has grown at around 2.1% per year since 1999, while broadband penetration has on average risen by about 2.4 percentage points per year (note the distinction between % growth rates and "percentage point increases"). The implied impact of such changes in broadband penetration is a 0.26% increase in productivity, or roughly 1/8th of the actual average annual productivity growth rate. While the calculated impact of broadband seems rather high, is more modest than the spill-over effects of fixed-line penetration estimated by Röller and Waverman for the 1970-1990 time

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[22] An interesting issue here is that relative to estimating the model as (a) OLS in levels, and (b) fixed-effects in levels, the R-squared from the first-differenced regressions is much lower (usually in the 0.3 to 0.35 range), whereas the R-squared from the levels regressions are much higher (0.8 without fixed effects and 0.98 with fixed effects). However, the Root Mean Squared Error of the regressions is far lower in first-differences than for any specification in levels. Additionally, estimates obtained in levels whether or not we are using fixed-effects do not provide economically believable results: for example, the coefficient on non-ICT capital falls to 0.11 (using the entire 1980-2007 period), and the coefficient on ICT capital is almost as high. It would thus seem that there is a time-series issue related to persistence in the regressors that might affect the levels estimation.

[23] These estimates are based on the assumption of a zero "base" effect for broadband penetration.

period. Given that broadband is a proxy for the diffusion of networked ICT, the resulting estimates seem believable.

3.28 It is also worth bearing in mind that over the period that broadband has become more widely diffused, ICT has contributed a very significant proportion of US productivity growth (33 percent), as measured in growth-accounting studies. A major proportion of this growth has come about in ICT-using sectors, and it seems possible (even likely) that the increase in "networked ICT" has been a major enabler of this productivity boom in ICT-using sectors. The perhaps puzzling aspect of the results, however, is that measured Total Factor Productivity growth in ICT-using sectors in Europe has been more modest, even in countries like Denmark that have had quite rapid diffusion of broadband (and of ICT generally).

3.29The major econometric question surrounding the model revolves around the remaining simultaneity bias in the model. We turn next to a detailed discussion of this simultaneity bias issue.

Simultaneity issues

3.30The issue of simultaneity can be addressed both in an intuitive way and by use of more formal techniques such as Instrumental Variables. One major issue here is whether or not one can find valid and strong instruments for the IV regressions. We have used standard techniques suggested for first-differenced regressions, and while these techniques produce IV parameter estimates that are not very different from the OLS estimates obtained previously, there are some issues with weak instruments that suggest the IV approach is not without its own significant limitations in this instance.

3.31At an intuitive level, the parameter estimates obtained are from regressions of growth rates against growth rates. If one were to look at the determinants of the broadband diffusion variable (the annual change in broadband penetration) over the period 1998-2007, the level of initial productivity (the productivity level in 1998) is highly predictive of the subsequent speed of broadband diffusion, but the growth rate of productivity is not. The regression reported in Table 12 assumes that there is no causality from broadband diffusion to productivity, so that the productivity growth variable is an exogenous regressor. At the very least, there is no support for the thesis that there is a one-way causality flowing from *productivity growth* to the speed of broadband diffusion.

Table 12: Broadband growth rate regression parameter estimates, 19982007

	Coefficient	Standard error	t-stat	P>t
Productivity growth rate	-16.9761	11.0452	-1.54	0.127
Initial productivity (1997)	0.7199	0.0725	9.93	0.000

Note: R^2 is 0.57 and the root MSE is 1.91.

3.32One can also see from Table 13 that productivity growth fluctuates but that the increase in broadband penetration is not affected by these fluctuations in productivity. At least for the time period that we examined, there is no evidence of significant common shocks to productivity and to broadband deployment. The "dot.com" bust of 2001 seems to be a shock that affected both the ICT sector and aggregate productivity growth, but the causality was from the ICT sector to the aggregate economy. Instead over the period that we examined, broadband appears to have been akin to a technology "shock" that originated in the ICT sector, and affected the entire economy. The timing and amplitude of this technology shock differs according to the level of initial productivity in OECD countries, with richer countries getting there first, but these differences in diffusion rates are explained by initial productivity levels rather than contemporaneous productivity shocks.

Table 13: Average growth rates for productivity and broadband penetration

Year	Productivity	Broadband penetration
1998	1.50%	0.00
1999	1.66%	0.20
2000	2.78%	0.51
2001	0.96%	1.46
2002	2.09%	1.99
2003	1.61%	2.66
2004	2.22%	3.74
2005	1.14%	4.28
2006	1.44%	4.20
2007	1.18%	3.54
Total	**1.66%**	**2.15**

3.33The previous literature on the returns to infrastructure investment and on economic growth might also provide some insight here. For instance, while Röller and Waverman (2001) show that controlling for simultaneity is important, their full simultaneous equations model still produces implausibly high estimates of the impact of telecommunications, unless and until country fixed-effects are introduced into the model. Subsequently they do show that introducing the full system of equations does have an impact on their estimates in one of their specifications, but the major reduction in the magnitude of the "implausibly high estimates" is from removing the spurious correlation effect (which can be done through techniques such as introducing fixed effects or first-differencing).

Instrumental Variables techniques

3.34Using the approach of Holtz-Eakin (1992), twice-lagged first differences were used as instruments for the potentially endogenous variables: growth rate of ICT capital, and changes in broadband and voice penetration. Two specification tests fail to reject the null hypothesis that the regressors are exogenous.[24] Alternative valid instruments might be provided by the twice lagged levels of the first-differenced variables. Again specification tests using these variables as instruments fail to reject the null hypothesis. Further, results from first-stage regressions show that twice-lagged differences appear to be stronger instruments than the twice-lagged levels. Quite likely, neither of these instrumental variable strategies is without its problems.

3.35 In the context of dynamic panel data models, the twice-lagged-differences approach has been criticised for producing very high variances around the parameter estimates (the variables usually being instrumented in such models are lagged dependent variables). The small size of the cross-section used in this study might also affect the asymptotic properties of the IV estimator that uses twice-lagged differences as instruments (Holtz-Eakin, Newey and Rosen (1989)).

3.36Table 14 below reports the results from the IV and OLS regression.[25] The parameter estimates are very close. Specification tests and tests for over-identification fail to reject the null hypothesis or any of the instruments.[26]

Table 14: Comparison of OLS versus IV parameter estimates

	OLS (Table 10)	IV
Non-ICT capital stock	0.3774	0.3548
	(7.20)	(8.19)

24 We also used additional instrumental variables — two indexes of entry regulation intensity in the telecoms sector and aggregate network industry regulatory intensity as reported by the OECD. Since these are on a scale from 6 to 0, with 6 indicating the greatest extent of regulation, the negative of these variables in levels appear to be quite well correlated with growth rates for broadband penetration. Tests for over-identifying restrictions were then implemented and failed to reject the additional instruments.

25 These regressions have been estimated under the constraint that the base broadband effect is zero, but even if the constraint were relaxed, the conclusions would remain the same.

26 A similar IV regression for just the period 1998-2007 also produces OLS and IV parameter estimates that are fairly close together (the coefficient on broadband (MEDHIGH) is 0.0021 (significant at 5 percent) compared to the OLS estimate of 0.0018, although the p-values for the Hausman-Wu test is 0.11, closer to being significant at least at the 10 percent level).

ICT capital stock		0.0584	0.0605
		(2.98)	(2.17)
Broadband penetration	BASE	0	0
	MEDHIGH	0.0013	0.0010
		(2.28)	(1.39)
Voice penetration		0.0006	-0.0010
		(1.80)	(-1.10)
Constant		0.0030	0.0076
		(0.94)	(1.90)

Note: Tests of endogeneity and overidentifying restrictions were run on the instrumental variable regression. The p-value for the Wu-Hausman F test is 0.15, the p-value for the Durbin-Wu-Hausman chi-sq test is 0.147. The p-value for the Sargan N*R-sq test is 0.21. T-statistics reported in parentheses.

3.37While the IV approaches pursued here are far from ideal, and the availability of suitable and strong instruments remains a significant issue, there is no apparent reason for believing that simultaneity bias plays a major role in generating the high apparent returns from broadband that we report here.

3.38Lastly, there is an issue of important omitted variables that are quite correlated with broadband deployment. These omitted variables, however, are quite likely to be other ICT-related variables. Our entire thesis here, however, is that broadband diffusion is a proxy for the spread of networked ICT into the wider economy.[27]

3.39Considering all this, we adopt final values of 0 for our "base" broadband effect and 0.001 for the "MEDHIGH" effect. We next turn to a discussion that may help illustrate why these two effects are believable.

4Case study: Sweden and Italy

4.1Italy and Sweden provide an interesting contrast in terms of countries that have very different levels of ICT development, even though their actual levels of income and productivity are not that far apart. What is apparent, however, is the economic reversal of fortune between the two countries. From 1980 to 1997, Italian productivity growth was significantly faster than Swedish productivity growth. From 1998 to 2007, however, Sweden's productivity growth has been

[27] Two further regression analyses were carried out: (a) a regression analysis that looked at the years 1998-2007 and included the change in PC penetration rates as a regression variable, and (b) an analysis that assumed that split the effect of ICT into (a) the "pre-networked" phase as represented by changes in personal computer penetration and changes in voice penetration, and (b) the "networked phase" where broadband is taken to represent the effect of marrying the voice network with the PC network. With respect to (a) the original results with respect to broadband held good — with the broadband coefficient for medium and high ICT environments increasing to 0.002, and the coefficient on PC penetration being insignificant. With respect to (b), PC, voice and broadband were all found to be significant. The further elaboration of this model remains a work in progress.

much faster than Italy's. Sweden's performance has actually improved significantly, whereas Italy's performance has declined dramatically.

Table 15: Comparison of Italy and Sweden

	Italy	Sweden
GDP per hour worked (2007, USA=100)	81	85
Average annual productivity growth,19801997	1.96%	1.38%
Average annual productivity growth, 19982007	0.39%	2.32%
PC penetration, 2006	36.7	88.00
Broadband penetration, 2007*	17.10	31.20
% of population with no internet skills, 2007*	58%	22%
% of enterprises receiving internet orders, 2007*	4%	26%
% enterprises purchasing on the internet, 2007*	29%	72%

Note: (*) These figures are sourced from "Preparing Europe's Digital Future" i2010.

4.2Many complex factors are at work here, but it is clear that Sweden has emerged as an ICT leader whereas Italy has not. In fact, in Italy, the demand for broadband appears to have slowed at a relatively low level (18 percent), and the ratio of Swedish to Italian broadband subscriptions has actually risen in recent years.

4.3One could argue that because broadband penetration is lower in Italy, Internet and broadband-related activities by businesses and individuals are being held back. Yet at the same time, the difference between Sweden and Italy on such measures as Internet selling and purchasing, and the proportion of the population with no Internet skills are far more striking and dramatic than would be suggested just by the difference between Italian and Swedish household broadband penetration.

4.4Indeed, a look at some further statistics prepared by the European Commission shows something interesting. Whereas Italy ranks 15th out of 27 EU countries on broadband penetration (in 2007), the country ranks between 20th and 25th on most measures of Internet usage. Thus the problem of middling levels of ICT development in Italy does not seem to be one of an inadequate supply of broadband alone, but at least equally a problem of demand. Italians are not significantly poorer than Swedes, yet there is a striking difference in their propensity to use ICT technology other than cell phones. Simply put, Italy appears to be a much more business-conservative society in terms of embracing technology than Sweden and this conservatism might be exacting a price in terms of foregone economic growth. Another way of looking at the comparison between Italy and Sweden is that Sweden, like some other Northern European countries and the United States, has found a new recipe for growth. Sweden's ability to do so has thus resulted in the process of convergence between Italy and Sweden—the process by which Italian GDP per hour worked increased from 67% of the Swedish level in 1960 to 115% of the Swedish level by 1990 — has gone into reverse. Sweden has become an innovation economy whereas Italy has not.

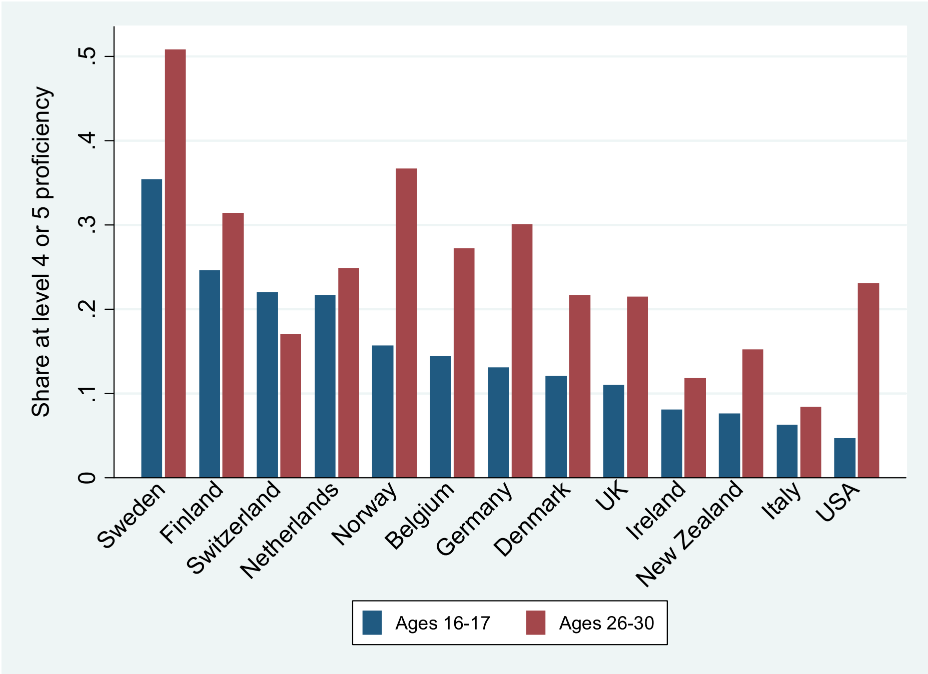
Table 16: Ranking of Italy and Sweden out of 27 EU Countries on Internet measures

Metric	Italy	Sweden
Broadband Penetration as % of population	15th	4th
E-mail sending	23rd	5th
Using Internet for information about goods and services	25th	2nd
Reading online newspapers	20th	4th
Internet banking	21st	4th
E-Commerce as % of enterprise turnover	17th	5th

Source: European Commission, "Preparing Europe's Digital Future", i2010.

4.5Yet another way of looking at the issue is that Sweden has an all-round excellent ICT and Internet eco-system. Sweden also has a significantly better level of educational attainment in the population than Italy. For example, according to a recent research report by the Federal Reserve Bank of San Francisco, the International Adult Literacy Surveys conducted in 1994, 1995 and 1998 found that Swedes in both the 16-17 age group and the 26-30 age group were more likely to fall into the "high proficiency" category of literacy and skills than their counterparts in any other country. Italians in the 16-17 age group finished just ahead of their American counterparts. However, Americans in the 26-30 age group scored significantly higher than Italians, because of a catch-up effect created by higher college enrolment rates in the United States compared to most other countries.

Figure 3: Adult Educational Attainment by age group



Source: Federal Reserve Bank of San Francisco, "Can Young Americans Compete in a Global Economy", *Economic Letter* 2008-22 (July 18^{th}, 2008).

4.6In many respects, our present research on broadband and the research we conducted for Connectivity Scorecard 2008 and Connectivity Scorecard 2009 have emphasised the role of deep-seated structural factors in driving ICT attainment. Where the eco-system surrounding broadband deployment is not supportive, there are likely to be two effects: (a) slower and delayed broadband adoption rates, and (b) reduced effectiveness of what broadband is deployed. Our econometric estimates are effectively capturing (b).

4.7Consider for example a country in which broadband is made freely available to households, but where user skills are low, and where businesses are very reluctant to change their processes in order to accommodate new technological possibilities. Here, households may be reduced to surfing the Internet for foreign content and foreign materials, but because of the rigidities in the business sector, the impact on the domestic economy would be reduced significantly. Thus the productivity benefits from this type of lop-sided broadband deployment might be nugatory.

4.8In the comparison of Italy and Sweden, Sweden had many positive attributes that allowed broadband to diffuse more rapidly and more completely than in Italy. Further, because there was a supportive ecosystem, the impact of broadband rippled rather quickly into a wide swathe of the economy. In Italy, the much less supportive ecosystem has perhaps not only slowed down the adoption rate of broadband, but may also have dampened the economic potential of existing broadband diffusion.

4.9What does this mean for policy-makers? Clearly there is a lesson here that one-sided broadband-focused policies are unlikely to be effective. Countries such as Italy may have to take a wider-ranging view of broadband as part of an ICT eco-system; they will have to pay attention to not just broadband deployment, but to broadband skills. They will have to find ways to break down resistance at the business level, and address resistance to change among older sections of the population. These are not easy measures, particularly not in a political sense. But they may be necessary measures for Italy and similarly-placed countries to move to a truly innovation-driven stage of growth. The factors that caused Italy to catch up with and even overtake nations such as the UK or Sweden between 1960 and 1990 are no longer present. Innovation offers a way of reviving economic growth, but in order for innovation to take hold, changes to traditional systems and ways of working may be required.

4.10 It may be the case, as we hinted in the Executive Summary, that over time, the deployment of an innovation like broadband will create its own demand and induce businesses and individuals to change their modes of work, and to acquire new skills and new perspectives. Yet it seems almost certain that the benefits from a pro-active and wide-ranging innovation policy will be realised significantly more quickly than relying on such an “if you build it, they will come” view of the world.

4.11Despite all the advantages that it already possessed, Sweden has actually followed a pro-active policy in broadband deployment. The country appears to have followed an intelligent broadband policy. Certainly subsidies and targeted infrastructure funding have been used, but this appears mainly to have been done in areas where the market was unlikely to provide the infrastructure itself. The idea behind Swedish broadband policy has been to complement the market, rather than replace it. Further, Sweden appears to have gone farther than even its well-developed Nordic neighbours in benchmarking ICT attainment and ICT progress. It is an irony that a country that already had so many favourable attributes for the development of a broadband-driven economy has actually also followed one of the most careful and deliberate ICT development programmes in Europe.[28]

5 Concluding Thoughts

5.1 The econometric analysis finds that broadband[29] has contributed a very significant proportion — perhaps 10 to 20 percent — of productivity growth in some OECD countries. Yet the econometric analysis also finds that in countries that had the lowest propensity for ICT (as measured by personal computer penetration rates averaged over the time period) the impact of broadband on productivity growth is not apparent.

5.2 Our assumption here is that the PC penetration provides a meaningful basis for grouping countries according to some notion of general ICT diffusion or attainment.[30] The findings suggest:

- The countries with the lowest PC penetration rates offered the least favourable general environment for broadband diffusion. Not only has broadband generally diffused more slowly in these environments, but the broadband diffusion that has occurred does not seem to have impacted on productivity;

- However, when one moves to the group of countries that offer a moderate to good ICT environment, broadband diffusion has been faster and the impact of what broadband has diffused has been very significant. In other words, the economic impact of adding a broadband connection is greater in these countries, and more broadband connections have been added;

- In this last group of countries, the model predicts that if broadband penetration increased by just 1 more broadband line per 100 individuals, the impact on GDP could range from $160 million in Finland (or $32 per individual) to $12 billion in the United States (or nearly $40 per individual). If the United States improved its penetration rate of broadband by 10

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[28] See for example, Information Technology and Innovation Foundation (ITIF), "Explaining International Broadband Leadership", Washington DC, May 01, 2008 for a detailed description of international broadband policies.

[29] To be more precise, we mean the spread of networked ICT as embodied by broadband.

[30] There is also a remarkable correlation between the rankings of countries in Connectivity Scorecard 2009 and any of (a) average PC penetration rate over 1998-2007, (b) PC penetration rate in 1998, and (c) PC penetration rate in 2006 (often the last year for which data are available).

broadband lines per 100 individuals (thus achieving the penetration rate already achieved in some parts of Northern Europe), the spill-over into the wider economy could results in $120 billion of additional GDP, or $400 per American.[31]

5.3Econometrics is inherently limited by its requirement to use historical data. Thus it is difficult to answer with absolute clarity the question about whether the lack of broadband-related productivity effects in the “low ICT” countries (as we have classified them) are just a matter of time. This may be so. It may be that broadband itself drives the creation of the complementary factors that are required to support its economic effectiveness. However, as we strongly argue, policy-makers should not rely on “due course” and the “fullness of time” for these effects to arrive. Some countries are in particular need of discovering new sources of growth, and the current economic crisis ought to provide an impetus for these countries to make the deep-seated changes that are required in order to achieve the transition to becoming truly innovation-driven economies. These countries should not just be promoting broadband deployment, ideally through market-conforming means, but also investing heavily in complementary skills and assets, which help people and businesses to use the available broadband infrastructure more effectively.

5.4Even for the countries where broadband has already had an impact, there are some lessons and some important warning signs. First, providing there are no diminishing returns to broadband, policies that promote broadband are policies that promote productivity, innovation and economic growth. Innovative ability is an important source of comparative advantage for advanced OECD economies. Thus policies that promote innovation and encourage investment in advanced infrastructure are the right ones; however, as many commentators now acknowledge, it cannot just be about infrastructure. The same infrastructure may well, in skilled hands, yield many times the returns that it would yield otherwise. Second, even within countries such as the United States and United Kingdom, advanced and ICT-savvy countries, there is an internal digital divide. This digital divide has previously been portrayed purely in terms of access to infrastructure, but as we and several other commentators now agree, there is also a divide in usage and skills that needs to be urgently addressed.

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31 Note: The estimated impact of broadband reflects what the historical data tell us regarding the value of adding broadband lines, provided these broadband lines are added in the right type of broader ICT and economic environment. We do not define this “right type of environment” in any absolute sense.

5.5There has been much debate about broadband funding in stimulus packages. The economic crisis of recent months has brought about a dramatic change in the way people perceive the role of government in the economy. The change in perceptions has also affected the politics of broadband deployment. Governments, such as in the UK, are now willing to contemplate large-scale public participation in the construction of Next Generation Access Networks, whereas once the goal was to find the right regulatory mix to promote such investment. Additionally, goals such as "broadband for all" and a "universal service mandate" for broadband provision are being increasingly mentioned in the public debate. The goals of expanding the reach of infrastructure are laudable, but they would have significantly greater economic benefit if they were also accompanied by policies that boosted the ability and incentives of people and businesses to creatively use that infrastructure.

6Bibliography

Anderson, T. W. and Cheng Hsiao. "Estimation of Dynamic Models with Error Components." *Journal of the American Statistical Association* Vol. 76 No.375 (1981): 598-606.

Aschaeur, D. A. "Is Public Expenditure Productive?" *Journal of Monetary Economics* Vol. 23 (1989): 177-200.

Barro, Robert J. "Economic Growth in a Cross Section of Countries." NBER Working Paper No. 3120, 1991.

Basu, Susanto, John Fernald, Nicholas Oulton and Sylaja Srinivasan. "The Case of the Missing Productivity Growth: or, does Information Technology explain why Productivity Accelerated in the United States but not the United Kingdom?" *NBER Macroeconomics Annual* Vol. 18 (2003): 9-63.

Commission of the European Communities. "Preparing Europe's Digital Future i2010 Mid-Term Review." Commission Staff Working Document Accompanying document to the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Vol. 3 ICT Country Profiles (2008).

Committee on Appropriations, US House of Representatives. "Summary: American Recovery and Reinvestment, Action and Action Now!" Press Release, January 15 (2009).

Crandall, Robert William and C. L. Jackson. *The $500 Billion Opportunity: The Potential Economic Benefit of Widespread Diffusion of Broadband Internet Access.* Washington DC: Criterion Economics, 2001.

Crandall, Robert William, C. L. Jackson and H. J. Singer. *The Effect of Ubiquitous Broadband Adoption on Investment, Jobs, and the US Economy.* Washington DC: Criterion Economics, 2003.

Crandall, Robert, William Lehr and Robert Litan. "The Effects of Broadband Deployment on Output and Employment: A Cross-sectional Analysis of US Data." *Issues in Economic Policy, The Brookings Institution* No. 6 (2007).

Garbacz, Christopher and Herbert G. Thompson Jr. "Mobile, Fixed Line and Internet Service Effects on Global Productive Efficiency". *Information Economics and Policy* Vol. 19 No. 2 (2007): 189-214.

Garbacz, Christopher and Herbert G. Thompson Jr. "Broadband Impact on State GDP: Direct and Indirect Impacts." Working Paper, 2008.

Garcia-Milà, Teresa and Therese J. McGuire. "The Contribution of Publicly Provided Inputs to States' Economies." *Regional Science and Urban Economics* Vol. 22 No.2 (1992): 229-241.

Garcia-Milà, Teresa, Therese J. McGuire and R. H. Porter. "The Effect of Public Capital in State Level Production Functions Reconsidered." *Review of Economics and Statistics* 78 (1996): 177-180.

Greenstein, Shane M. and Pablo T. Spiller. "Modern Telecommunications Infrastructure and Economic Activity: An Empirical Investigation." *Industrial and Corporate Change* Vol. 4, No. 4 (1996): 647-665.

Haskel, Jonathan E., Chiara Criscuolo and Gustavo A. Crespi. "Information Technology, Organisational Change and Productivity Growth: Evidence from UK Firms." *Centre for Economic Performance, LSE/CEP Discussion Papers* (2007).

Holtz-Eakin, Douglas, Whitney Newey and Harvey S. Rosen. “Estimating Vector Autoregressions with Panel Data.” *Econometrica* Vol. 56 No. 6 (1988): 1371-1395.

Holtz-Eakin, Douglas. “Public-Sector Capital and the Productivity Puzzle.” *The Review of Economics and Statistics* Vol. 76, No. 1 (1994): 12-21.

Jorgenson, Dale W., Mun S. Ho and Kevin J. Stiroh. “The Sources of Growth of US Industries.” In *Productivity in Asia: Economic Growth and Competitiveness,* edited by Dale W Jorgenson, Masahiro Kuroda and Kazuyuki Motohashi, 23-75. Edward Elgar Publishing, 2007.

Koutroumpis, Pantelis, “Broadband Infrastructure and Economic Growth: A Simultaneous Approach”, *mimeo*, Imperial College, London (2008).

Lehr, William, Carlos A. Osorio, and Sharon E. Gillett. “Measuring Broadband's Economic Impact”. Final Report Prepared for the U.S. Department of Commerce, Economic Development Administration National Technical Assistance, Training, Research, and Evaluation Project #99-07-13829, February 2006.

February, 2006 In the proceedings of Telecommunications Policy Research Conference, Washington DC, 2005.

Norton, Seth W. “Transaction Costs, Telecommunications and the Microeconomics of Macroeconomic Growth.” *Economic Development and Cultural Change* (1992): 41-175.

Oliner, S. D. and D. E. Sichel. “The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?” *Journal of Economic Perspectives* Vol. 14, No. 4 (2000): 3-22.

Röller, Lars-Hendrik and Leonard Waverman. “Telecommunications Infrastructure and Economic Development: A Simultaneous Approach.” *The American Economic Review* Vol. 91, No. 4 (2001): 909-923.

Romer, Paul M. “Endogenous Technological Change.” *Journal of Political Economy* Vol. 98 No.5 (1990): 71-102.

Schreyer, Paul. "Computer Price Indices and International Growth and Productivity Comparisons." *Review of Income and Wealth* Vol. 48, No. 1 (2002): 15-31.

Shideler, David, Narine Badasyan and Laura Taylor. "The Economic Impact of Broadband Deployment in Kentucky." *Regional Economic Development* Vol. 3 No. 2 (2007): 88-118.

Solow, Robert M. (1987) "We'd better watch out," *New York Times* (July 12), Book Review, 36.

Timmer, M. P., G. Ypma and B. van Ark. "IT in the European Union: Driving Productivity Divergence?" *Research Memorandum GD-67* Groningen Growth and Development Centre (2003).

Varian, Hal, Robert E. Litan, Andrew Elder and Jay Shutter. "The Net Impact Stady: The Projected Economic Benefits of the Internet in the United States, United Kingdom, France and Germany." Version 2.0 (2002). http://www.netimpactstudy.com/NetImpact_Study_Report.pdf.

Waverman, Leonard and Mel Fuss. "Canada's Productivity Dilemma: The Role of Computers and Telecom." In Bell Canada's Submission to the Telecommunications Policy Review Panel, Appendix E-1, 2005.

Principal Data Sources

The Conference Board, Total Economy Database, 2008.

Groningen Growth and Development Center, Growth Accounting Database, 2008.

ITU, World Telecommunication/ICT Indicators Database, 2008.