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ICT and Australia's Productivity Growth: Understanding the Relationship[1]

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ABSTRACT *This paper explores how information and communication technology has influenced Australia's productivity performance in the 1990s, drawing on research undertaken by the Australian Department of Communications, Information Technology and the Arts. The research uses four different approaches to assess the robustness of earlier Australian research. All approaches point to the fact that the impact of ICT on Australian productivity is greater than previously thought. Of the approaches, the GPT modelling appears to offer the greatest potential to meet the further policy challenges in a transition to an information society.*

Keywords: productivity; innovation; general purpose technology; economic growth.

Introduction

This paper is about the impact of information and communication technology (ICT) on Australia's productivity performance. It draws on a body of research being undertaken by the Australian Department of Communications, Information Technology and the Arts (DCITA) into that relationship. The research uses a range of methodologies and frameworks to provide different insights into the complex process of economic growth and transformation. Its empirical focus is on Australia, and its aim is to inform policy relating to the new 'knowledge-based' markets enabled by ICT.

This paper starts by discussing ICT as technology. It then discusses the increasing plurality of approach found in the growth literature. This leads us to consider how the choice of an analytical framework might generally influence the findings on technology and growth. This examination of alternative frameworks provides a context for a discussion of the research findings, and their implications.

ICT and Technological Change

ICT is defined in different ways for different purposes. Conceptually it is a technology, not a piece of hardware, such as a desktop computer or peripheral.[2] Investing

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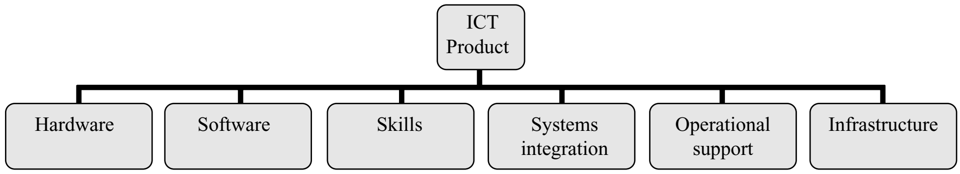

Figure 1. ICT is a composite good.

in a technology involves more than an off-the-shelf purchase of hardware or software: it involves investing in the complementary assets (skills, management systems, organisational structures and strategies) that together provide a return to the investor. The 'opportunity cost' concept suggests that the return is possibly better measured in terms of long-run competitiveness rather than the more conventional return on investment.[3] The composite nature of ICT is shown in Figure 1.[4]

A broad definition of ICT is increasingly used by analysts. Such definitions include the human capital aspects of ICT along with the physical. For example, Lievrouw and Livingstone[5] see it as combining 'the artifacts or devices that enable and extend our abilities to communicate; the communication activities or practices we engage in to develop and use these devices; and the social arrangements or organisations that form around the devices and practices'.

Nevertheless, particularly for modelling purposes, it may be defined more narrowly. For example, Nicholas Carr in his recent book, *Does IT Matter*,[6] argued that IT investment did not carry strategic benefits, because computers are the ultimate homogeneous commodity. But our work and that of others[7] suggest that this argument is flawed when the role and nature of ICT in transformation, innovation and technological competitiveness is built into the analysis.

It is widely acknowledged that of today's technologies, ICT is evolving and diffusing most rapidly. ICT is also acknowledged to be a transformative agent, enabling other forms of innovation by increasing the opportunity set. We would therefore expect that findings relating generally to the impact of technology on growth can, with some care, be used to make deductions as to the impact of ICT on productivity.

The Complexity of the Growth Process

The plurality of approach found in the growth literature is testament to the complexity of the growth process and of its relationship to technological advance. Thus, for example, while technological change generally underlies growth, growth can also foster technological change. While these two-way impacts can generate 'virtuous-circle' productivity bonuses (or externalities) in some economies, such benefits seem to depend on having the appropriate economic and institutional environments.

Moreover, the characterisation of the environment presents special problems. For example, it is particularly hard to conceptualise and classify such factors as knowledge and social adaptability, let alone quantify them. In consequence, growth research faces significant challenges, especially in identifying and measuring the institutional characteristics that are thought to sustain innovation and growth in the long-run.

The complexity of growth process and the difficulty in quantifying such key variables as innovation and technological change have implications for its modelling. As yet, no formal model can adequately represent the key aspects of the growth process. How then should one start research into how the evolution and diffusion of ICT in Australia may have contributed to our economic and productivity growth?

Growth Accounting

It is common to approach the study of growth with the analysis of growth accounting data. For Australia, growth accounting studies have established that capital or labour accumulation are not the key source of Australia's strong and sustained growth since the 1990s. The major contributor is the total factor productivity growth (TFPG), a measure of the interaction between the input factors. In technical terms, TFPG is the residual left when the input growths, appropriately weighted and summed, are subtracted from aggregate output growth.

The chief advantage of growth accounting is the ready availability of data for modelling. Its weakness is the lack of any theory to guide the use of TFPG. As there is no theory of TFPG, it is used in different and inconsistent ways by different researchers. The accounting process provides no information on how technological change, scale and efficiency effects might interact or respond to economic incentives. As a simple accounting method, it can provide 'stylised statistics' on differences between growth rates over time and between economies. However, issues such as data quality limit its development into a theory able to explain all stylised facts relating to growth.

In Australia, the Australian Bureau of Statistics and the Productivity Commission extended growth accounting to separate the contribution of quality-adjusted ICT capital from other capital. Technological advances embodied in ICT capital were captured as a 'capital deepening' impact on labour productivity. The residual impact, TFPG, may be taken to represent disembodied technological change, although its relationship to the evolution and diffusion of ICT remains problematic.

Choosing a Framework

An issue for DCITA researchers was whether the assumptions that underlie the growth accounting data were causing the contribution of ICT to be understated. To avoid such bias, the DCITA research used a range of analytical frameworks. Some of these frameworks are substitutes, and so compete for influence in the same policy space. Others are complementary, combining different perspectives to give deeper understanding of the change process.

Competing frameworks, for example those of neoclassical and evolutionary growth theories, can yield conflicting prescriptions for growth policy. The largely hands-off prescriptions of the former reflect its depiction of market competition as the end-state equilibrium with efficient resource allocation. The more hands-on prescriptions of the latter reflect its depiction of market competition as a disequilibrium process necessary for dynamic efficiency.

Not all frameworks compete for policy space, instead informing on different aspects of growth. The range of traditional and new approaches is expanding, with researchers seeking insights from economic historians and other social sciences. These new approaches add value in understanding technological–economic interactions such as the new economy boom–bust and related productivity change effects.

If the process of abstraction and reduction from complexity to workable methodologies is to be guided by deeper, more holistic, understanding of growth,[8] the appropriate start for DCITA research might be the literature on growth and technological change, to explore framework theorising that captures the stylised facts on growth, especially the theorising (and related modelling) on the role of technological and social innovation in sustaining growth.

Stylised Facts from Economic History

The 'First' Economic Revolution: Agriculture[9]

Economic historians have attributed significant leaps in the quality of human life to transformative productivity-enhancing innovations. They find the domestication of animals and crops generated the productivity surplus that enabled the growth of the early civilisations from around eight millennia BC. They also document how realising the potential benefit of these technologies required innovation in social structures, and how the interaction of incremental technological and social innovation had led by the first millennium to several civilisations whose technological and economic structures bore little resemblance to those of the nomadic hunter gatherer societies from which they evolved.

Douglass North was one of the first to draw attention to the economic significance of this first great transformation of human society, which he describes as the 'first economic revolution' and attributes to the evolution and diffusion of animal and crop domestication technologies.

The term 'revolution' seems odd given the slow pace and incremental nature of the change process. Indeed the process is evolutionary, building continuously on existing structures, each single step being predictable in itself. Indeed, because of its incremental nature, growth economists liken the change process to a 'trajectory', with the cumulative impact of transformative processes being so large and fundamental as to appear 'revolutionary to the pre-change society were it to be visible to them'.[10]

Recent advances in our understanding of these early civilisations have led to other relevant findings. Research[11] shows that the competitiveness of the civilisation depended on technological rather than social sophistication. Those civilisations that lacked access to the key technologies of the time were vulnerable to domination by emerging competitors.

The 'Second' Economic Revolution: Industry

While continued technological change has underpinned today's prosperity, the advances in technology have been unevenly distributed in time and space. Periods where major social and technological innovations interact to transform civilisation are rare. North sees the wedding of the industrial revolution and science in the mid-nineteenth century as heralding the 'second economic revolution', the transformation from an agricultural to an industrial society, with secondary production, and located in cities, dominating economic activity.

Despite the scope and magnitude of technological change during the transformation, North claims that the associated institutional and social changes had the greater impact. He asks the economic profession to place greater emphasis on institutional change, pointing to how institutional change can drive gains in living standards by dramatically reducing the transaction costs in both established and emerging markets.

A 'Third' Economic Revolution: Information?

The close relationship between technological and institutional change is apparent in the present day evolution and diffusion of modern ICT. The magnitude of the changes occurring in telecommunications is clearly visible in Australia today. Some see the ICT-enabled productivity gains in greater scale and complexity in production driving the transformation from an industrial to an information society, with tertiary service activities increasingly dominating economic activity and widespread societal change as the new technologies enable globally integrated production systems.

We cannot know whether the world is now experiencing the early stages of a 'third economic revolution'. It is far too early to compare today's transformation with the completed transformations of North's first and second economic revolutions. Nevertheless, it is perhaps significant that today's ICT seems to be playing a transformative role somewhat akin to that of printing and the telegraph in the second economic revolution, and the development of language in the first. ICT is radically improving our capacity to collect, analyse, utilise, distribute and exchange information. It transforms industries by: improving operational efficiency; enabling product and service innovation; and enabling new business models.

Technology Cycles and Uneven Innovation

The empirical observation that the advent of new technologies generates long cycles of industry-led innovation dates back 70 years to research by Schumpeter and Kuznets.[12] Schumpeter's 'creative destruction' metaphor and Kuznets' 'law on innovation', describing the rising and declining phases of induced innovation over a period as long as 40 years, bear legacy to their empirical investigation.

These cycles of innovation induced by technological discovery have been confirmed by economic historians, and different phases in economic growth can be traced to the advent of particular technologies. Economic historians, including Freeman and Perez,[13] have chronicled the different era, and use their detailed knowledge of history to date the advent and decline of particular technologies. Both provide evidence to support the contention that we are now entering the information age. Paul David[14] has pointed to the delayed impact of productivity gains from information technology based on analogy with the productivity change associated with electrification, thus denying the Solow paradox[15] by suggesting that the productivity bonus would not be contemporaneous with a peak in its diffusion, but follows it. The delay between productivity impact and technological evolution/diffusion is now widely accepted, and considered a part of the innovation process that is triggered by the arrival of a 'general purpose technology' or GPT with ICT presently the most dominant GPT.[16]

However, this cyclical phenomenon associated with innovation has been long documented. Arora *et al.* describe how, during the industrial revolution, many 'general specialities' as Stigler labelled them, exploited scale economies in production. Stigler's examples of general specialities include railroads and shipping, the

London banking centre, specialised production of intermediate materials, and capital goods.[17] Similarly Rosenberg analyses how capital good technological convergence led to significant economies in the production of general purpose machine tools embodying fundamental principles of shaping, bending and cutting metals that could be applied to a host of industries such as firearms, bicycles, sewing machines and automobiles.[18] The succession of technologies each building on the earlier underlies the concept of structured technology that dates to Nelson and Winter's technological regimes, Freeman and Perez's technoeconomic paradigms and Mokyr's macro inventions.[19]

The Bresnahan and Trajtenberg 1995 paper not only gave the concept its present day name of GPT but econometrically demonstrated that particular GPTs can give rise to positive dynamic externalities. It suggested *prima facie* grounds for market intervention to ensure a socially optimal rate of take-up, and it led to a burst of research aimed at further developing the concept. Its development has been further progressed by the team of Richard Lipsey, Kenneth Carlaw and Cliff Bekar, whose key findings have recently been published as *Economic Transformations: General Purpose Technologies and Long Term Economic Growth*, hereafter LCB.[20] LCB propose, and others agree,[21] that a GPT must have four properties: wide scope for further significant improvement and elaboration; applicability across a broad range of uses; the potential for use in a wide variety of products and processes; and strong complementarities with existing and potential new technologies.

LCB categorise GPTs according to broad function, seen over the long span of historic time. Think of the sequence stone age, bronze age, iron age, steel age to the composites of this era. These represent GPTs of the material type, all transforming production over time. GPT processes have been widely studied. For GPTs in the power category, Richard Nelson showed how replacement of the water wheel by the Corliss steam engine transformed social structures in North Eastern USA at the turn of the seventeenth century. Paul David has done the same for factory electrification. The replacement of one GPT by the next occurs as a sequence of incremental steps, none of which is individually radical. And while transformation necessarily involves creative destruction in the sense that over time, a new technology irreversibly replaces an older one, the change need not be disruptive in the economic or social dimensions. Societal investment in most GPTs has seen a massive complementary accumulation of physical capital. This is most clearly apparent in the transport-type GPTs, for example, the evolution and diffusion of motorised transport replacing animal-based transport. This transformation saw massive investments in road networks and associated facilities, and in new services, e.g. fuel (oil refineries, tankers, etc.) and garages etc.

Today ICT is accepted as the dominant transforming GPT. However, the expected complementary capital accumulation associated with ICT is less apparent than that of the other GPT categories. It is therefore not so surprising that the one-time New Economic sceptic, Robert Gordon, then asked whether ICT matched the great inventions of the past. Perhaps the query was prompted by the soft nature of the ICT complementarities, namely the hard-to-measure intangible forms of capital, including organisational capital, social capital, human capital or perhaps more broadly knowledge capital. Economic historian Mokyr and others see this as generally true of GPTs of the communication and information type, for example, the writing, printing and telegraph GPTs that preceded today's ICT.

Indeed, for Mokyr, it was the Enlightenment that underlay the industrial revolution, suggesting a very fundamental and direct role that these GPTs in the information and communication category have in social and economic transformation.

The global leaders of the ICT sector, including IBM's Palmisano[22] appear to understand the necessarily cyclical nature of industry-based innovation, and currently see a new phase of ICT-enabled innovation-based transformation about to commence with its benefits now available globally.

Framework Theories on Innovation and Growth

Theory plays a crucial role in economic analysis. It ensures that spurious relationships sometimes suggested by data are rejected. However the choice between theoretical frameworks can influence the research findings in various ways: for example by the form of analysis, the choice of variables, the admitted evidence and perhaps most importantly, the relative weightings attaching to various pieces of evidence exposed by the research.

The choice of theory is particularly important for growth analysis. Analysts might use growth accounting data within a neoclassical framework that is more applicable to (static) resource allocation than innovation-based growth. Better alternatives for innovation would include Solow's steady state growth model,[23] evolutionary theories, and theories relating to economics of information[24] and sometimes associated with the Austrian school.[25]

Neoclassical versus Growth Theorising

Solow's theory of Steady State Growth (SSG) popularised the empirics of growth.[26] MFPG represented shifts in the production function and capital deepening movements along the function until steady state growth when technological advance ceased. A huge research effort followed seeking to explain, by better input accounting, the residual, considered as 'a measure of our ignorance'.[27] Some prominent researchers such as Zvi Grilliches,[28] saw the residual as associated with knowledge growth, specifically through R&D and education. The difficulty in estimating quality change in these areas of social services is a significant issue for productivity measurement.

Richard Nelson in particular has emphasised the need for growth theorising to move beyond the competitive equilibrium theories of neoclassical economics, which can mislead growth policy. In 1982, with Winter, he pointed to stylised facts on technology-based growth, and the 'appreciative theorising' that can explain them.[29] In 1995, he called for formal modelling based on appreciative theorising to better inform growth policy.[30] In 2005, he details how the implications and thrusts of SSG theory differ from evolutionary growth theory, as growth theories that focus on an aggregate measure of growth, such as GNP per capita, are blind to what is going on beneath the aggregate, where differing rates of advance in different sectors, and the birth and death of industries are an essential part of the growth process.[31] The broad theory of economic growth that Nelson presents sees the process as involving the co-evolution of technologies, institutions, and industry structure. He cautions that careful empirical testing is required to establish what theorising can best guide growth policy research.

In terms of ICT investment, the empirical studies suggest that a key issue confronting firms in making ICT investment decisions is not the conventional economic one of choosing the optimal input combination, but rather the dynamic optimisation on timing and frequency of ICT upgrade.[32] This is consistent with GPT theory which suggests that ICT underlies the sustained growth in the innovation opportunity set.

The 'unexpected action at a distance' described by Basu *et al.* clearly distinguishes this evolutionary ICT concept from the neoclassical one.[33] And it certainly can give different answers to the question of importance. Neoclassical growth theory does not recognise the long-run potential importance arising from small inconspicuous beginnings.[34] Size *is* important. It is only when a technology begins to mature that it will make an observable contribution to growth. Assessing the importance of a GPT by the size of its contribution in its early state may thus mislead growth-oriented policy.

Metcalfe in 1997 showed how the TFP shifts in a production function are consistent with an evolutionary theory based on firm heterogeneity.[35] He goes on: 'but this is an exercise in the measurement of an *imagined* production function. It is a device for telling a production function story, no more no less'. At the heart of his criticism is the separability assumptions that underlie the statistical aggregation process. And he finds that the difference between the neoclassical growth theory and evolutionary growth theory matters, 'not least because it influences deeply our interpretation of the historical record, and our understanding of the channels through which policy initiatives shape economic growth'.

Information Economics: Markets as Disequilibrium Drivers of Change

The alternative view put by many of the Austrian School[36] is that information on so-called market failure is what drives innovation and economic growth. In this sense, static equilibrium is not a desirable or socially optimal state, as recognised by, for example, Schreyer in the *OECD Productivity Manual*.[37]

In the long run, the importance of knowledge, however defined, is increasingly seen as of critical importance in understanding economic change, and thus requiring the further attention of economists.[38] In this tradition, Metcalfe describes the challenge for empirical analysis:

> From the perspective of the growth–knowledge relation, markets take on a new light. We see them not as devices to optimally allocate given resources to given ends, but as institutions to facilitate change, to permit entrepreneurship, to encourage challenges to the established order. Thus they are devices for keeping the economy ordered, but out of equilibrium, they are frameworks that shape ongoing structural change.
>
> Nor are market institutions given. They have to be established, and their establishment, growth, stabilization and decline involve the investment of real resources in market making activity.[39]

The evolutionary school has links with complexity theory and knowledge management as, for example, detailed by Mark W. McElroy.[40] This is an area of growing importance, closely linked to ICT, and expected to be a driver of future productivity growth.

GPT Theorising

In this section we discuss a new form of growth theorising, based on the GPT concept introduced above. The theorising contains elements from both evolutionary and information economics. It is seen as particularly important in offering a route towards formal modelling of the growth process. We focus below on how the theorising establishes positive externalities for transforming GPT processes.

Arora *et al.* point out that GPT-based theorising is an example of a particular testable hypothesis that could be seen as a particular subclass of system-based analysis of innovation. In this they importantly distinguish innovative growth associated with economies of scope and general purpose technologies from innovative growth associated with specific large-scale innovations typically driven by economies of scale.

This distinction dates back to Adam Smith's 'the division of labour is limited by the extent of the market'. However, Arora *et al.* argue that the extent of specialisation depends on the breadth of application for a technology rather than the size of the market:

> if a specialised supplier is restricted to a single buyer, there is no advantage to specialisation that can offset the inevitable costs, transactions and others, involved. Specialisation advantages only arise if a supplier can serve a number of different producers at a nominal additional cost … In short, we suggest that markets for technology and specialised technology suppliers are more likely to arise in the case of General Purpose Technologies (GPTs).

Arora *et al.* go on to point out that the creation of new GPTs continues unabated, led by specialised science and engineering high-tech industries:

> The electronics industry, for instance has seen sustained increase in specialisation, as hardware, software and networking have become separate subdisciplines … Thus today and in the past, industrial development is marked by the creation of whole new bodies of specialised knowledge and by whole new industries selling to many others.

The appropriate policy is likely to depend on the industry context. The seminal Bresnahan and Trajtenberg article demonstrates that in any division of labour involving specialised firms that serve a number of users, there are both horizontal and vertical externalities. The vertical externalities arise because the more efficient the suppliers, the greater the value of the investments that users make in using the supplied input. Conversely, the greater the investments that users make in using the supplied input, the greater the payoff to firms that supply the input. The horizontal externalities arise because in any division of labour, the upstream supplier will supply more than one downstream user. Thus, any improvement in cost or quality of the supplier will benefit the users. In turn when a given user makes an investment that enhances the value of the input, this will induce the supplier to make complementary investments to improve cost or quality. The benefits of improvements will spill over to other users.

GPT theorists find that the implication of these externalities is that the resulting market outcomes may not be efficient and that collective action, such as user–producer research consortia, would improve welfare. Another is that the actual process through which a division of labour can emerge is likely to be strongly conditioned by history and chance—i.e. an industry that becomes vertically integrated early in its history is more likely to remain that way even when the cost-minimising structure involves the division of labour. Conversely, once a division of labour begins to unfold, the industry structure may evolve away from integration even if that is cost minimising.

These insights can help explain changing global competitiveness. Arora *et al.* speculate that the large and diversified US industry, compared to other countries, has largely been responsible for important GPTs, such as software, semiconductors and the like.

> one could even argue that the US competitiveness in the world today is comparatively higher in sectors that have exploited the size of the domestic market to gain industry-wide economies (software, biotechnology, semiconductors) than in sectors that exploited it to enjoy economies of scale at the level of the individual firms (e.g. automobiles).

These new specialisations, disciplines and practices are not created by the market forces acting alone. The creation of new specialisation requires other forms of coordination. These coordination mechanisms can be seen as a form of collaborative planning, and are required for the new practices to become embodied in work and social life. Thus GPT theorising links back to information and evolutionary economics.

Australian Growth Theorising

In Australia the lead roles of the Productivity Commission in productivity research and in promoting microeconomic reform require some versatility in theorising, as the growth theorising that informs innovation policy differs from the neoclassical theorising that guides microeconomic reform. Under neoclassical theorising, competition ensures the allocative efficiency of market equilibrium. In contrast, growth theorising sees competition as the disequilibrium process that drives the change, innovation and economic progress, that is competition is important for dynamic efficiency. The Productivity Commission's productivity research has used New Growth theories for example, by Gretton *et al.* in 2002,[41] and its theorising on microeconomic reform recognises dynamic efficiency.[42] Its theorising does not, however, acknowledge the claims of Ahn[43] and others that policy which trades off some allocative efficiency for more dynamic efficiency may prove socially optimal in the medium to long run, and has been slow to recognise the transformative GPT characteristics of ICT. Nevertheless, the Productivity Commission acknowledge that 'Depending on the context, reform can be as much about developing and implementing appropriate government intervention as it is about removing it' recognising that 'Government support is required to underpin innovation'.[44]

Some ICT Scepticism Preceded the DCITA Research

The early Australian research on ICT and productivity in Australia was undertaken by the Productivity Commission as part of its on-going productivity research. We first describe these findings. Next we contrast them with the US experience to expose the significant differences by year-end 2003. This is followed by a description of the subsequent in-house and sponsored research by DCITA using different frameworks.

Early Australian Research Found Strong ICT Uptake Not the Source of Strong Productivity Performance

Productivity research at the end of the 1990s used the Solow steady state growth model.[45] The research found that there was a very significant TFP shift in the production function in the mid-1990s, one that exceeded the TFP shift associated with the US New Economy revival. The research found the source of the TFP shift was most likely due to delayed impacts of microeconomic reform. It did not explicitly test for 'New Economy' impacts of the ICT type.

Specific research into the impact of ICT on Australia's productivity performance followed. The research,[46] like that of the OECD, Finland, UK and Canada, followed the US approach of splitting the capital deepening effect into ICT deepening and other effects. This Australian research, like that of the US, found ICT capital deepening was a significant contributor to our labour productivity growth. However, when the difference in average MFPGs over the early and late 1990s growth cycles was examined, it was MFPG rather than capita deepening that most explained the 1990s surge in Australia's productivity growth.

Australia's participation in OECD firm-level analysis of the impact of ICT on sources of growth was led by the Productivity Commission.[47] This work produced a similar magnitude for the impact of ICT on acceleration in the mid-1990s. The similarity between the firm-level econometric analysis and non-parametric aggregate growth accounting supported the earlier finding that ICT contributed but about 0.2 percentage points of the 1% acceleration in MFP between the growth cycles, and led the Productivity Commission to conclude that the key underlying cause of Australia's productivity in the mid-1990s was microeconomic reform.

In short, the finding was that although ICT was a significant contributor to our strong productivity growth, the strength of Australia's productivity acceleration could not be explained by Australia's strong uptake of ICT. A survey of the Productivity Commission and other research, published in the Economic Record, found two other proximate sources of the productivity acceleration, namely 'openness' and 'R&D' each of which had made a higher contribution.[48] The article, while recognising that the various impacts were not additive, supported the earlier claim that ICT was a significant, but not a major factor in Australia's strong productivity performance.

US Research—A Reversal of Initial New Economy Scepticism

In the mid-1990s, after two decades of slowdown, US MFPG showed signs of a dramatic revival. Coincidently, after four decades of evolution, modern ICT had become integral to the work and leisure activity of most people. The explosion in connectivity, especially apparent in the Internet and 'globalisation', prompted an increased awareness of an ICT-productivity relationship. The result was a popularisation of the notion of an 'Information Revolution' and the 'New Economy'.

The utopian properties attributed by some to an ill-defined 'New Economy' were treated with extreme scepticism by most economists. Five years on, the hype but not the reality of the underlying transformation had vanished—the unrealistically high expectations associated with over-inflated values of technology stocks, had suddenly and dramatically turned. Nevertheless, by year-end 2003, the productivity-raising impact of the 'Information Revolution' had been acknowledged by leading economists the world over.[49]

Unlike Australia, the initial US scepticism about the role of ICT use in lifting productivity growth declined as the US moved into the new millennium with sustained high levels of TFP growth. At the OECD, the complementarity between technology, organisational innovation and institutional reform was increasingly recognised, perhaps most significantly in the policy directions recommended by the OECD following their growth project in 2001. The 'stick to fundamentals' prescription of mainstream economics was joined with a policy emphasis on innovation, enterprise, skills, and on *realising the potential of ICT*.[50]

Finally, in August 2003, the most prominent and long-standing of the New Economy critics, Professor Robert Gordon, accepted that the persistence of the US productivity growth could be taken as confirming the revolutionary nature of ICT and he modified the growth accounting method to take into account the GPT characteristics of ICT.[51] This can be seen as marking the end of the US controversy as to the key role of ICT in productivity growth. Nevertheless, disagreements over the details of productivity measurement have persisted.

The most convincing evidence of the importance of ICT in the US, however, may be from firm level analysis rather than modified growth accounting. In 2003, Brynjolfsson and Hitt reworked their comprehensive data on 527 of the largest US companies over 1987–94 to see whether the non-contemporaneous productivity response often associated with a GPT investment shock might explain the delayed productivity response in the US. They found it might, concluding:

> While the late 1990s saw a surge in productivity and output as well as a corresponding surge in computer investment, it is important to note that our analysis is based on earlier data from the late 1980s and early 1990s. This earlier time period did not enjoy extraordinary growth in the overall economy. If computers indeed require several years to realize their potential growth contribution, the economic performance in the late 1990s may, in part, reflect the massive computer and organisational investments made in the early 1990s.[52]

Similar firm level results came from a range of other countries. By year end 2003, the complementarity between ICT, management and innovation in driving MFPG had been firmly established not only in the US, but also in many of Australia's competitor economies.

In Canada, research by Surendra Gera and Wulong Gu used the GPT concept in explaining the role of ICT. Their research firmly demonstrates that, for Canadian firms, ICT complements organisational change and human capital:

> We find that while ICT is productive on its own, it is more productive in firms that combine high levels of ICT with high levels of organisational change. The firms that combine ICT with organisational changes have a high incidence of productivity improvement and have high rates of innovation. These findings seem to suggest that to be successful, firms typically need to adopt ICT as part of a 'system' or 'cluster' of mutually-reinforcing organisational approaches. We also find that ICT and human capital are complements in the service sectors. The firms that combine high levels of ICT and high levels of worker skills have better firm performance.[53]

A general view at year-end 2003 was that economies that had invested in ICT were the strongest performers. Australia seemed to be the exception, not so much because it had not invested in ICT, but rather because the traditional analytical frameworks used for the analysis did not accept that the strong productivity performance of the Australian economy was related to its strong ICT uptake.

DCITA Research Uses Alternative Analytical Frameworks

Using Statistical Methods to Explain MFPG—or Letting the Data Speak

While it had been generally acknowledged that ICT has played some part in Australia's recent good productivity growth performance, the previous growth accounting research had left much of the productivity growth unexplained. The unexplained growth was commonly attributed to micro-economic reform, with an implied suggestion that the Australian experience may have been somewhat of an exception to that observed overseas.

The two DCITA studies discussed in this section seek to explain the residual MFP growth using regression and correlation techniques to distinguish and measure the impacts of the potential drivers of Australia's productivity growth. The first study, *Productivity Growth in Australian Manufacturing,* was published in March 2004 by the former National Office of the Information Economy. The second, *Productivity Growth in Service Industries,* was published by DCITA in August 2005.

The key finding of these studies is that for many parts of the manufacturing and service sectors, ICT made a much more significant direct contribution than was hitherto suspected. For manufacturing, the research suggests that between 56 and 80% of MFPG in manufacturing during the 1984–85 to 2000–01 period was due to technological factors, while institutional-economic changes may explain between 20 and 44% of MFPG. For service industries, after taking away the effect of increased capital spending per worker, technological factors (the ICT revolution in particular) accounted for between 59 and 78% of productivity growth.

The wide disparities in growth rates between industries observed both within manufacturing and within service sector industries enabled the statistically significant regression findings. Moreover, the nature of the disparities provides an intuitive explanation to the finding, namely that technological factors were more important drivers of productivity growth than the institutional-economic ones. This is because changes in institutional-economic factors, such as improved labour market flexibility, improved competition in product and capital markets or rising education standards, would tend to affect productivity growth rates relatively evenly, and not cause wide variations in growth rates. Thus, the wide dispersion of sub-sectoral productivity growth rates observed is an indication that the main drivers of productivity growth were the technological ones.

Explanations for the differences in productivity growth rates were sought by regressing the growth rates against a range of explanatory variables. The variables used to capture technological impacts were: R&D intensity, capital intensity, labour productivity growth in other OECD countries (reflecting international technological trajectories), inputs of locally produced electronic equipment and telecommunications services, and inputs of the above plus professional and engineering services. The variables used to capture institutional effects were: reduction of tariff protection, reduction in the number of days lost per employee due to industrial disputes, the share of university graduates in the industry's workforce, the share of persons with post-school qualifications (from universities or technical colleges) in the workforce, changes in the above mentioned education variables.

The research framework found similar patterns in the manufacturing and service sectors. We report them only for manufacturing. Here the productivity growth rates across the sector industries were accounted for by four or five of the variables. When the technological variables were included in the regression, the relationships almost always turned out to be highly significant (R^2 ratio above 0.7 and sometimes even above 0.8). Since our interest was in decomposing the variations that were not due to capital deepening, and thereby obtaining an estimate on the contribution of other factors to MFP growth, we discounted the impact of change in capital per worker. This showed that in regressions with high R^2 ratios, technological variables usually account for over 80% of explained variance and institutional variables account for less than 20%.

A Growth Accounting Method for Transforming GPTs

As discussed above, the growth accounting method is the most widely used method for productivity analysis and readily extended to separate out the impact of ICT capital. Nevertheless, its wide use is not a reliable indication of the robustness of the method for examining the GPT effects of ICT. Thus, DCITA, as part of its research into ICT and productivity, commissioned two prominent productivity practitioners, Dr Denis Lawrence and Professor Erwin Diewert, to investigate the robustness of the early growth accounting findings on Australia's ICT take up.

The focus of this research, which was undertaken in two stages, was whether the competitive market assumptions underlying standard growth accounting would cause the contribution of ICT to Australian productivity performance to be understated, especially given the sustained and rapid rate of technology change indicated by the large persistent declines in cost of computing power.

Findings from the first-stage investigation were published by DCITA in January 2006 as Chapter 3 of *ICT and Australian Productivity: Methodologies and Measurement.* It describes how the consultants modified the traditional tools of conventional productivity analysis to take account of the unique characteristic of ICT, including the sustained and rapid falls in the real price of computing. This approach directly addresses the concern that the equilibrium assumptions that underlie conventional growth accounting are ill-suited to measure the 'Information Revolution' characteristics of ICT.

Using a recent advance in econometric analysis of productivity, the appropriateness of two traditional productivity assumptions (constant returns to scale technology, and 'perfectly competitive market' pricing) was tested. With appropriate data, this approach should have indicated whether the conventional methodologies, when applied to Australia's National Accounts data, had understated significantly the contribution of Australia's early uptake of ICT to our strong 1990s productivity growth. However, this part of the analysis was inconclusive, because the data quality did not meet the high standard required by this approach.

The method was also able to inform on whether the standard user cost formula that underlies conventional growth accounting reflected the value of ICT to Australian producers. The evidence on this issue was unambiguous and conclusive, demonstrating that there are above normal rates of return to ICT capital:

> … across all industries examined … ICT contributes more to output than its cost to producers. This result comes through uniformly despite manifold data limitations in some sectors. This means that the standard growth accounting productivity measures will not adequately capture the 'Information Revolution' characteristics of ICT.

To address the data issues that limited the first stage investigation, the consultants, with help from ABS, constructed an alternative aggregate productivity database for Australia. The new database better met the consistency tests required by this method and enabled statistically significant findings, subsequently published by DCITA in 2006 as *Estimating Aggregate Productivity Growth for Australia: The Role of Information and Communications Technology*. This report concludes as follows:

- TFP growth in the expanded market sector of the Australian economy has been very good over the past 45 years comprising a high average annual TFP growth over the 12 years to 1972 of around 1.66%, more modest average growth of 1.22% over the period 1972–95 and then very high average TFP growth of 1.85% over the last decade;
- this compares with ABS multifactor productivity average annual changes of 1.19% per annum for the seven years to 1972, 1.05% for the period 1972–95 and 1.55% per annum for the last decade;
- the D–L database produces somewhat higher productivity growth rates on average than the narrower ABS multifactor productivity series demonstrating the importance of including the additional service sectors included in the D–L database—to put this in perspective, the D–L database covers around 95% of value added in the economy whereas the narrower ABS coverage picks up around two-thirds of value added;
- there is evidence of modest increasing returns to scale (1.07 on average) in Australia's expanded market sector with a correspondingly modest mark-up of around 8%;
- the large majority (around 85–90%) of TFP growth is accounted for by technical progress rather than increasing returns to scale;
- applying the more detailed econometric model to the aggregate level D–L database has confirmed that ICT contributes more to output than its cost to producers—in fact, our estimates indicate that ICT inputs are worth around 40% more to producers in terms of marginal product than they pay for them;
- the undervaluation of ICT inputs by producers is likely to be due to a combination of market disequilibrium, innovation related externalities and intangible investment in human capital associated with investment in ICT; and,
- the results of this study indicate that greater attention to the uptake of ICT will have an important role in further improving economic growth.

Distinguishing Trend and Cycle—Was Productivity Surging or Growing?

The elimination of transient and business cycle effects from estimates of trend productivity was a significant feature of US research into its New Economy productivity analyses. In Australia, the early research paid little attention to this issue. The reason was that the ABS averaging methodology was expected to eliminate any significant cyclical effect.[54]

The relationship between new technologies, business cycles and productivity cycles is both complex and poorly understood.[55] Thus there was doubt as to whether the observed productivity surge was in some way a feature of the business cycle, or the result of the particular methodology that removed the cyclical effect from the trend estimate. Different choices of method can give quite different results, even to the extent of generating false surges, and there is no consensus as to which single measure might be least vulnerable to error. In such circumstances, it may be appropriate that the ABS, for reporting purposes, would standardise, choosing the Aspden growth cycle average for official use. But there can be no certainty that analyses using only the Aspden average will generate robust indicators of the change pattern in trend productivity.

Therefore, as part of its research, DCITA examined whether cycles might have influenced the assessment of the early research that suggested that the ICT had a significant but relatively small impact on productivity performance as measured by its impact on the acceleration in MFPG over the two 1990s growth cycles. This research was reported in 2006 by DCITA in Chapter 5, 'Reviewing the Evidence' of *ICT and Australian Productivity: Methodologies and Measurement*.

The chapter reports that cyclical explanations may well account for the large jump in MFPG between the early and late 1990s. The low average MFPG over the 1988–89 to 1993–94 cycle may reflect the presence of the strong recession of the early 1990s, while the high average MFPG over the 1993–94 to 1998–99 cycle may be largely due to the absence of a recession. The 1.1 percentage point difference between these averages would be then explained as business cycle variation, and so be an unreliable indicator of acceleration in trend productivity. Indeed, the Quiggin estimate,[56] which took specific account of business cycle effects, gave a much lower estimate, one that is comparable in magnitude, but not timing, to the Error Correction Model (ECM) estimate that we prefer.

Productivity researchers had previously rejected a cyclical explanation, claiming that econometric research based on the ECM method supported an acceleration of about 1% in MFP in the mid-1990s. We tested this view using alternative trend methodologies including X11 smoothing. This is a worthwhile test, since in theory the ECM can strip out cyclical from trend. An ECM study by Dowrick[57] previously found the change in trend MFPG was 1.4 percentage points per year. This high estimate contrasted with a much lower estimate of 0.8 by Quiggin using non-parametric methods. Quiggin attempted to take account of the macroeconomic impact of the business cycle. Since then, the ABS data have been revised and updated. Using ECM with the revised data, the Productivity Commission[58] reported an acceleration in trend MFPG of 0.76%, much lower than the earlier Dowrick estimate.

We report that the ECM estimates are consistent with Australia experiencing strong *growth* in trend MFP over the 1990s, but not a strong mid-1990s *acceleration* needed for a productivity 'revival'. Explicitly factoring in the much earlier revival suggested by all the ECM studies indicates the ECM and Aspden estimates of MFPA are not substitute measures of an MFP acceleration. Instead, our finding is that the Aspden estimates of a mid-1990s MFPA capture a moderation in the 1990s business cycle, while the ECM estimates suggest the acceleration to a high but steady productivity growth over the 1990s occured in the late 1980s.

We conclude that these different measures of productivity give a consistent picture of Australia's productivity growth over the 1990s. It is one of strong steady growth in trend MFP, but with a strong business cycle trough depressing MFPG in the early 1990s Aspden cycle and strong business cycle plateau lifting the MFPG of the following Aspden cycle.

Resolving the Solow Paradox: Can GPTs Cause Productivity Cycles?

To determine whether ICT take-up affects productivity, it is first necessary to know the underlying mechanism. That mechanism will determine the relationship between a particular pattern in the ICT take-up and that in the productivity. In particular, it can indicate when and how productivity might change in response to a given change in ICT, other things being equal. Without knowledge of the underlying mechanism, one cannot easily rule out the possibility that ICT is a source of any productivity gain, nor can one rule it in as the cause.[59]

The normal approach to this dilemma is the use of experience and theory to make judgement as to the expected cause and effect. Thus, the early growth accounting research on ICT had implicitly assumed that ICT-induced productivity gains would occur on or soon after ICT take-up. The absence of such effects was interpreted as 'no effects' so that the more complex effect of ICT was not counted. While this process is commonly used and generally reliable for economic analysis, its application to the study of technology, innovation and economic change is problematic. It may be robust for established markets but fragile for emerging ones, where empirical methods deriving from the seminal research of Rogers are commonly used.[60]

To determine whether the conventional neoclassical framework is the appropriate one for analysing the impact of ICT, DCITA commissioned Carlaw, a member of the Lipsey, Carlaw and Bekar team that developed the GPT concept, to determine whether the Australian productivity experience was consistent with the role of ICT as a GPT.

The research was completed in two stages. The findings of the first stage were presented to the Asia Pacific Productivity Conference in Brisbane in July 2004, and published by DCITA as Chapter 4 of *ICT and Australian Productivity: Methodologies and Measurement* in January 2006. A subsequent more extensive analysis, by Carlaw and Lipsey, was presented by Carlaw to the International Workshop on Evolutionary Modelling, University of Queensland, July 2005 and is reported in the DCITA Occasional Economic Paper, *General Purpose Technologies and the Information Economy: An Evolutionary Approach to Macroeconomic Modelling*.

Carlaw builds formal three- and four-sector GPT simulation models that capture the key stylised facts known from the growth literature. The modelling meets the challenges that Nelson identifies for growth theory. In these models, technological change is directly measured, and not proxied by TFPG. The TFP calculations generated by the simulations of the theoretical model *inter alia* enable common assumptions of traditional and New Growth theories, such as returns to scale and returns to knowledge in production, to be tested. The key characteristics of the model are summarised as follows:

> GPTs arrive at randomly determined times with an impact on the productivity of applied R&D that is determined by the amount of pure research knowledge that has been endogenously generated since the last GPT and elements of randomness. The three sources of randomness outlined above imply that in the short term outcomes are influenced by the particular realizations of the random variables, allowing the average growth rate of output over the lifetime of each successive GPT to differ from that of its predecessor. However, the

> average growth rate over long periods of time in which several GPTs succeed each other is determined by the accumulated amount of pure knowledge. This is partly endogenous (determined by the allocation of resources to pure research), and partly exogenous (determined by random factors affecting the productivity and timing of those resources). Furthermore, while some GPT driven research programs are richer than others, there is no reason to expect that successive GPTs will always either accelerate or decelerate growth on average over their lifetimes. There is no expectation that each new GPT will produce a productivity bonus in the form of an acceleration to the rate of productivity growth. The model is solved using numerical simulation which requires calibrating parameter values. We choose values in order to achieve long run average growth rates of approximately 2% and GPT arrival rates of on average 30–35 periods. The qualitative results are robust to a wide range of parameter values that meet the restriction specified in the model.

The properties of the model's solution are:

> The model generates a non-stationary equilibrium, such that neither the levels nor the rates of change of the endogenous variables converge to constants. There is a transitional competitive equilibrium in every time period, given the expected marginal productivities of inputs in each sector. But because of technological advance, the nature of the spillovers, and the absence of perfect foresight, the marginal products change from one period to the next in ways that are not anticipated. Although growth never stops, a very productive new GPT can accelerate the average growth rate over its lifetime while a less productive new GPT can slow it. This last characteristic allows us to focus on the historical, path dependent and variable pattern of growth.

The second stage analysis uses a more realistic GPT simulation, and is able to show that Australia's pattern of productivity growth is consistent with the predicted characteristics of a GPT, in that productivity falls when the GPT is rapidly diffusing, and rises as the GPT matures. The research also confirms that technologically-driven patterns of economic change cannot be determined from observations on the aggregate statistics, because of the complex interaction effects between GPTs. Although not stated in the paper, it seems that the consistency of the Lipsey–Carlaw GPT modelling with the Australian productivity data could be interpreted as indicating that ICT take-up has had an important albeit complex impact on Australia's productivity growth.

DCITA Research Implications

The use of very different frameworks provides a variety of perspectives on how ICT can influence growth, and the different ways of approaching the analysis. Together these frameworks give greater understanding of the complexity of the growth process, and the need to eschew simple analytical approaches. Taken together, they suggest that the understanding provided by the early Australian research on ICT and productivity was deficient and that the impact of ICT on Australia's productivity performance is greater than was previously thought. Such a conclusion is supported by the DCITA firm level research, including research by Ovum on *Productivity and Organisational Transformation: Optimising Investment in ICT*[61] and *The*

Australian Mining and ICT industries: Productivity and Industry Growth;[62] by Howard Partners on *Digital Factories: the Hidden Revolution in Australian Manufacturing*[63] and by Opticon and ANU on *Achieving Value for ICT: Key Management Strategies*.[64]

Yet, despite the very different frameworks used, some common and important messages for researchers and policy makers arise. Some key messages for researchers are:

- it is highly desirable to use a range of frameworks to investigate complex phenomena such as economic growth, while working to develop a more integrated approach;
- there is a critical need to better establish a theoretical framework that can guide empirical analysis on growth. In that, the formal modelling of Carlaw and Lipsey may be a front runner. In the long run, this might see very significant change in the economic profession itself, as, with the other social sciences, it begins to grapple with complex issues associated with the transformation to an information society.

The Potential of a GPT Theoretical Framework for Growth Models

Of the different frameworks, the GPT theorising framework seems to hold most promise. It seeks to better capture the real world complexity of economic growth by endogenising technological and institutional factors. Economic models have often abstracted from these factors, not because they are considered unimportant, but because the analytical, statistical and data issues verged on the intractable.

The Carlaw and Lipsey model presently only goes part way toward the ultimate goal of building a GPT analytical framework, in part because of data issues facing the development of proxy variables for technology and knowledge. At present to distinguish TFPG from technological change, Carlaw used investment specific technological change estimated from the National Accounts productivity database. Another issue challenging further development is aggregation. Carlaw and Lipsey presently abstract from the agent heterogeneity and market selection process that they see as driving innovation and growth at the microeconomic level to avoid aggregation issues.

An advantage of the model is its focus on ICT diffusion in the face of Knightian uncertainty. Some form of GPT modelling is required to distinguish non-GPT technology drivers for GPT drivers, and to examine the nature and drivers of the GPT-based innovation, and the interaction between GPT drivers. With increasing focus on innovation as a productivity driver, leading economists bemoan the lack of attention to diffusion, e.g. Hall and Khan state:

> it is diffusion rather than invention or innovation that ultimately determines the pace of economic growth and the rate of change of productivity.[65]

The impact of networking effects enabled by ICT has been particularly hard to establish by traditional methods at the macro level, with mixed findings from some econometrics showing strong returns and others showing little. This study suggests caution in the use of such methods because it suggests that: (i) criteria that test whether short-run ICT-based productivity bonuses are contemporaneous with ICT investment are flawed; and (ii) that the more efficient communication and information processing technologies of today are largely responsible for the speed up in the rate of technological change.

Lastly, the model's potential stems from its more realistic representation of the nature of the information revolution. As stated by Quah, the impacts on the social side are as important as those on industry.

> The key lesson for the New Economy is that endogenous growth results from the interaction of demand and supply characteristics, not just production-side developments.[66]

The more inclusive GPT framework not only satisfies the Quah criterion for understanding growth—albeit at an aggregate level—but also is consistent with the Metcalfe critiques in not ignoring the role of consumption. It is a more realistic representation of growth through the service economy and knowledge workers. At a time of rapid ICT-enabled social transformation, it may provide a more useful framework for uncertain forward effects than historic growth accounting.

Policy Implications

Despite very different approaches, the DCITA researchers share common themes and support particular directions for future productivity research in this, the information age.

First, the studies in very different ways point to likely shortcomings in previous Australian productivity research in appropriately addressing information economy issues. The broad perspective of the in-house research exposes key issues for research, and indicates the broad range of methodologies that are being applied to investigate the sources of economic growth.

The Diewert–Lawrence research exposes the extent of measurement issues that arise in assessing the impact of ICT and confirms the other findings as to the significance of ICT for productivity growth.

The Carlaw–Lipsey research raises fundamental issues as to how to interpret conventional MFPG estimates in a period of innovative growth driven by a transforming GPT. It has significant potential as a way to address the issues being raised by growth researchers.[67]

The empirical review of the Australian evidence emphasises the need to fully understand and explore the data being used, and the care needed in separating cyclical and trend productivity change.

In all cases, the effect has been to suggest that conventional measures have most likely underestimated the role of ICT in Australia's strong productivity and economic growth.

Taken together, the studies suggest ICT is central to Australia's productivity performance. Jointness, complementarity, heterogeneity, technology and dynamics are key aspects of innovative growth and have often been excluded from previous analyses as being too difficult to model. Inclusion of these characteristics in economic analysis brings subtle differences to economic policy prescriptions. In particular, it suggests that a sole policy reliance on markets to achieve growth objectives might not be entirely appropriate. Rather today's economic reform calls for a more complex balance of responses and initiatives, with policy being sensitive and responsive to changing context. In this age of transition, responsibility for the transformations needed to realise the potential of ICT extends across all responsible government agencies. There is a common need to promote the new institutions and practices of an information society. This requires support of change in society, encouraging enterprise, institutional flexibility and resource mobility as appropriate in these times of unusually rapid and uncertain global change.

Notes and References

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46. Dean Parham, Paul Roberts and H. Sun, *Information Technology and Australia's Productivity Surge*, Productivity Commission Staff Research Paper, Canberra, 2001.
47. See Gretton *et al., op. cit.*
48. The estimation is detailed in Dean Parham, 'Sources of Australia's productivity revival', *Economic Record*, 80, 249, 2004, pp. 239–57.
49. Maddison, drawing on year 2000 research, puts the view that 'there has been a belated but positive payoff in macroeconomic productivity from a couple of decades of high investment in the "new economy". The fact that there have been no very evident spillovers as yet in computer-using industries may well be due to the costs of absorbing new technologies which have involved a large input of highly trained people, rapid obsolescence of equipment and skills, and some serious blunders'. He suggests that, 'in the longer run, when the new technology has

been fully assimilated, significant spillovers to other sectors of the economy may well occur', and 'there are grounds for hoping that progress may be faster than in 1973–95'. This view is entirely consistent with the unevenness in the trajectory of properties associated with the dynamics of innovation triggered by the emergence of a new phase of technological change. In other words, it is consistent with the GPT theorising (Maddison, *op. cit.,* p. 137).

50. OECD, *The New Economy: Beyond the Hype, The OECD Growth Project*, OECD, Paris, 2001, August. The 'realising the potential of ICT' element in the prescription can be seen as having a large overlap with the other three new elements: greater emphasis on innovation, enterprise and skills.
51. Gordon, *op. cit.* Even the most prominent and longstanding critic, Robert Gordon, changed from an ICT sceptic to an advocate. While Gordon's reversal followed statistics that ruled out the business cycle as a source of the high US MFPG, the persuasion of colleagues, many of whom considered ICT to be a GPT, appears also to have influenced his decision.
52. Erik Brynjolfsson and Lorin Hitt, 'Computing productivity: firm-level evidence', *Review of Economics and Statistics*, November 2003, available at: http://s.ssrn.com/sol3/s.cfm?abstract_id=290325.
53. Surendra Gera and Wulong Gu, 'The effect of organisational innovation and information technology on firm performance', *International Productivity Monitor,* No. 9, Fall 2004, abstract.
54. The ABS use a peak-to-peak criterion on the growth cycle data derived from its multifactor productivity (MFP) indexes to select suitable intervals over which the MFP growths can be averaged. Australia is alone in the use of this methodology, developed by Charles Aspden in 1989 and 1990.
55. The debate continues to this time, as evidenced by the 2005 paper into the fundamental issue of why productivity tends to be pro-cyclical by Robert Inklaar, 'Cyclical productivity in Europe and the United States, evaluating the evidence on returns to scale and input utilization', *Research Memorandum GD-7*, Groningen Growth and Development.
56. John Quiggin, 'The Australian productivity "Miracle": a sceptical view', *Agenda*, 8, 4, 2001, pp. 801–17.
57. Steve Dowrick, 'Productivity boom: mirage or miracle' in J. Niewenhuysen, P. Lloyd and M. Mead (eds), *Reshaping Australia's Economy: Growth with Equity and Sustainability*, Cambridge University Press, Cambridge, 2001, pp. 19–32.
58. Productivity Commission, *Trends in Australian Manufacturing*, Commission Research Paper, Canberra, 2003.
59. This fundamental fact is as true for changes in broad institution factors, such as those associated with economic reform, as it is of a GPT like ICT. This makes distinguishing between such causes difficult.
60. See for example, Bronwyn H. Hall, 'Innovation and diffusion', in Jan Fagerberg, David C. Mowery and Richard R. Nelson (eds), *The Oxford Handbook of Innovation*, Oxford University Press, 2005, ch. 17, pp. 459–85. The seminal work is by Everett M. Rogers, *Diffusion of Innovations,* 1st edition, The Free Press, New York, 1962 (4th edition, New York, 1995). A recent example of a recent adaptation is John Dimmick and Tao Wang, 'Toward an economic theory of media diffusion based on the parameters of the logistics growth equation', *Journal of Media Economics*, 18, 4, pp. 233–46.
61. Ovum, *Productivity and Organisational Transformation: Optimising Investment in ICT*, NOIE, 2003.
62. Ovum, *The Australian Mining and ICT Industries: Productivity and Industry Growth*, NOIE/DCITA, 2004.
63. Howard Partners, *Digital Factories: the Hidden Revolution in Australian Manufacturing*, DCITA, 2005.
64. Opticon and ANU, *Achieving Value for ICT: Key Management Strategies*, DCITA, 2005.
65. See Bronwyn H. Hall and Beethika Khan, *Adoption of New Technology*, University of California, Berkley Department of Economics Working Paper No. E03-330, May 2003, available at: http://econwpa.wustl.edu:8089/eps/dev/papers/0401/0401001.pdf.
66. Quah, *op. cit.,* summary.
67. In addition to cited works of the prominent researchers mentioned in the article, one would add Robert Solow, 'Growth theory and after', *R. M. Solow-Prize Lecture*, 1987 and 2001, Nobel e-Museum Laureates, available at: http://www.nobel.se/economics/laureates/1987/solow-lecture.html.