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Information technology and its changing roles to economic growth and productivity in Australia

Md. Shahiduzzaman [a,*], Khorshed Alam [b]

[a] Australian Digital Futures Institute and Australian Centre for Sustainable Business and Development, University of Southern Queensland, Australia
[b] Australian Centre for Sustainable Business and Development, Faculty of Business, Education, Law and Arts, University of Southern Queensland, Australia

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ABSTRACT

In this paper we describe our investigation of the role of investment in information technology (IT) on economic output and productivity in Australia over a period of about four decades. The framework used in this paper is the aggregate production function, where IT capital is considered as a separate input of production along with non-IT capital and labour. The empirical results from the study indicate the evidence of robust technical progress in the Australian economy in the 1990s. IT capital had a significant impact on output, labour productivity and technical progress in the 1990s. In recent years, however, the contribution of IT capital on output and labour productivity has slowed down. Regaining the IT capital productivity therefore remains as a key challenge for Australia, especially in the context of greater IT investment in the future.

1. Introduction

Since the late 1990s a significant number of studies have examined the contribution of information technology (IT) on productivity and economic growth, predominantly using data for the United States (US) (Jorgenson & Stiroh, 1999, 2000; Oliner & Sichel, 2000) and concurrently for other countries (e.g., Parham, Roberts, & Sun, 2001, for Australia). These studies have shown a strong contribution of IT capital on productivity and growth in the 1990s. In the 2000s, however, productivity growth has slowed down in most advanced countries (Dolman, 2009). Questions therefore arise on the appropriate role of IT investment on economic growth and productivity in the historical context. Moreover, there is a need to reappraise the role of IT capital in the present context to design intervention strategies for the future.

The present work aims at quantifying the contribution of IT capital to economic output, productivity and technical progress using Australian data for 1975–2011. The growth and productivity improvements in Australia during the late 1980s and 1990s have long sparked interest to researchers. Australia sustained a remarkable growth performance during the period of financial crisis in the 1990s – quoting the country as a 'miraculous' economy (Krugman, 1998). Productivity improvement is seen to be a major source of the robust economic performance and the IT revolution has been identified as the major contributor to the productivity performance during the period (Banks, 2001; Parham, 2005a; Parham et al., 2001). Cross-country studies identified a very strong contribution of IT capital on economic growth in Australia during the 1990s – just behind the much-noted US and the largest among the OECD countries (Colecchia & Schreyer, 2002). However, sceptics view the productivity surge in Australia in the 1990s as just a statistical illusion (Dolman, 2009; Quiggin, 2006).

* Corresponding author. Tel.: +61 045 882 3191; fax: +61 746 315 597.
E-mail addresses: MD.Shahiduzzaman@usq.edu.au (Md. Shahiduzzaman), Khorshed.Alam@usq.edu.au (K. Alam).

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Nevertheless, Australia's productivity performance has fallen short of expectations since the 2000s where the growth rates of multifactor productivity slipped down, on average, from 1.7% during the 1990s to 0.4% during the 2000s and to −1.3% in 2011 (ABS, 2012a). Therefore, the role of IT capital on economic growth and productivity remains a conundrum, especially for those who advocate that IT capital accumulation placed a profound impact on the productivity surge of the 1990s and also in the context of promoting greater IT investment in the forthcoming years. Hence, to enlighten this debate, there is a need to reassess the contribution of IT on productivity and economic growth in Australia with the use of historical and newly available data.

Significantly, there is little empirical research to shed light on the role of IT investment on productivity and growth, especially using the most recent data. Moreover, existing studies on causality analysis in this area are mostly relied on bivariate models, which impose limits on an accurate analysis due to the omitted variable problem. To overcome the issues, this paper implements a multivariate approach and employs the Toda and Yamamoto (1995), hereafter TY test, to explore long-run causality among the variables. The TY approach has several advantages over conventional tests for Granger causality. The approach obviates the need to pre-test for cointegration and is often preferred over the error-correction based tests – the latter tends to have a larger size distortion (Zapata & Rambaldi, 1997; Zhang & Cheng, 2009). In addition, given the viewpoint that IT investments have important spillover effects and may generate externalities (Levendis & Lee, 2012; Röller & Waverman, 2001), the possibility of an endogeneity between the variables of interest can be captured by implementing simultaneous equation modelling within the TY framework to explore the direction and sign of causality (Bowden & Payne, 2009; Shahiduzzaman & Alam, 2012; Squalli, 2007). Finally, with few aggregate models applied to capture the effects of IT investment on output and productivity developments in Australia, this study covers data from the mid-1970s to 2011, providing an overall understanding both on the recent and historical contexts.

The paper is organised as follows. Following this introduction, Section 2 provides a historical overview of economic performance and IT use in Australia. Section 3 gives a brief review of the theory and evidence. Section 4 illuminates the methodology and data and Section 5 presents the empirical results. Finally, Section 6 provides a conclusion and some policy implications.

2. Economic performance and IT use in Australia

Productivity performance in Australia was remarkable in the last few decades with a major resurgence in the 1990s (Parham, 1999). Indeed, apart from a short-lived business cycle downturn in the early 1980s, both labour and multifactor productivity have grown, on average, at a positive rate and the improvement was sustained during the period associated with the recession in the early 1990s (Fig. 1). The robust productivity performance of the Australian economy has led the gross domestic product (GDP) growth to hover around 3% on average in the long-term context (Fig. 1), which is a remarkable as compared to comparable advanced countries. It is viewed that higher productivity growth generally leads to periods of sustained economic growth and, consequently, improved standards of living. Understanding the underlying factors is of profound importance in the context of long-term prosperity and is, therefore, a major concern for policy makers.

Existing studies provide different factors for the acceleration of Australia's productivity growth in the 1990s (Productivity Commission, 1999). In general, they fall into two broad categories – one is the microeconomic reforms started in the mid-1980s and the other is the uptake of the latest IT in the 1990s (Parham et al., 2001). It is suggested that microeconomic policy reforms played a pivotal role in shaping a favourable environment for the Australian business sector to adopt new technologies and to put them to play a productive roles in the 1990s (Banks, 2001; Parham, 2002a; Parham et al., 2001). Fig. 2 shows the exponential growth of IT capital share to total capital from the mid-1980s – its timing and magnitude might have placed a significant impact on economic and productivity performances in the 1990s (Parham et al., 2001).

The deterioration of productivity and consequent economic performance in the 2000s, however, created a major concern. IT investment as represented by ‘Information Technology Gross Fixed Capital Formation’ in chain volume measures grew at

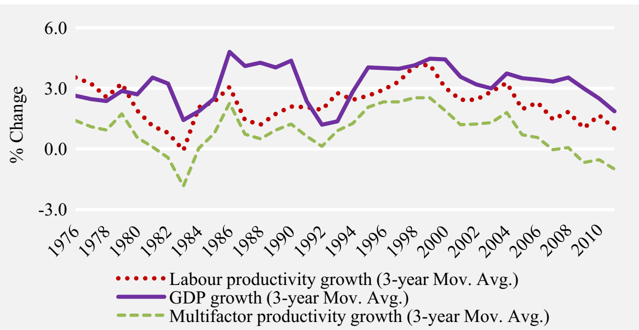

Fig. 1. GDP and productivity growth (3 year moving average), 1976–2011.
Source: GDP growth data – cat no. 5206, Table 30, Australian Bureau of Statistics for growth rates of gross domestic product: Chain Volume (Reference year 2009–2010) – % Change. Productivity data – cat. no. 5260.0.55.002 experimental estimates of industry multifactor productivity, Australia: detailed productivity estimate, Table 4, indexes (2009–10 = 100). Data extracted online from http://www.abs.gov.au/AUSSTATS/ on 11 September, 2012.

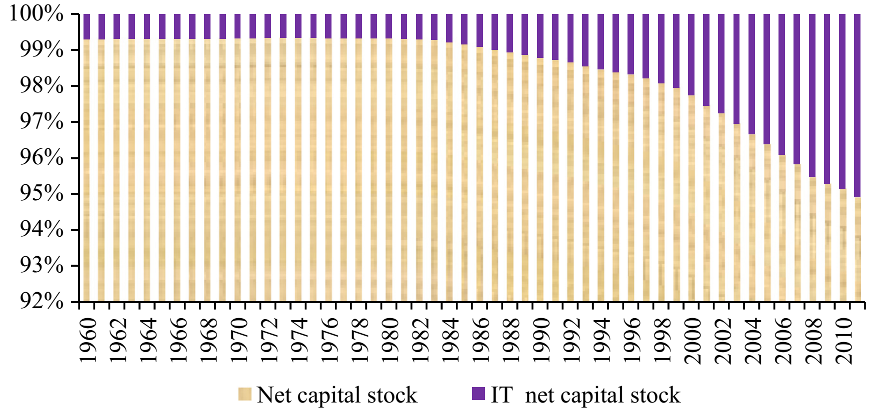

Fig. 2. Share of IT capital stock, 1960–2011.
Source: Cat. no. 5204, Table 70, ABS. Data extracted online from http://www.abs.gov.au/AUSSTATS/ on 17 August, 2012.

an annual average rate of 12.91% during 2001–2011 as compared to that of 12.87% over the period 1985–2000 (ABS, 2012b). During the period 2006–2011, the annual average growth rate of IT investment was 12.33% (ABS, 2012b). Therefore, the role of IT investment in the changing economic environment in the 2000s remains a puzzle. Dolman (2009) provided a possible explanation: the productivity contribution of IT capital might have slowed since 2000 as compared to the 1990s. It is argued that the contribution of IT was more like an enabler rather than the engine of growth and the IT had only played a moderate role in the productivity surge in the 1990s (Dolman, 2009). Overall, an empirical assessment of the effects of IT investment on economic growth and productivity remains relatively unexplored in Australia, especially using the recent data.

3. The impact of IT on output and productivity: theory and evidence

The impact of IT on productivity and output has been an ongoing subject of debate between 'new economy' believers and sceptics. A quarter of a century ago, Economics Nobel laureate Robert Solow quipped in the *New York Times Book Review* that 'you can see the computer age everywhere but in the productivity statistics (12 July 1987)'. In recent years, a number of influential studies claiming the strong role of IT investment on economic growth and productivity have emerged (Jorgenson, 2001; Jorgenson & Stiroh, 1999, 2000; Oliner, Sichel, Triplett, and Gordon 2000). Oliner, Sichel, Triplett, and Gordon (1994) once noted that 'the computer puzzle of the 1980s was more apparent than real' (p. 275). In 2000 the same authors placed IT at the centre of boosting productivity and growth in the 1990s in the US (Oliner & Sichel, 2000). Similar results were noted in the case of Australia and other advanced countries (Colecchia & Schreyer, 2002).

Growth models predict different mechanisms through which IT investment can be related to economic growth and productivity. A well-developed telecommunications structure decreases the cost of acquiring information and increases efficiency. The importance of information efficiency to investment and in turn to economic growth has been widely recognised in the literature (Stiglitz, 2002). The neoclassical growth model illustrates output as a factor of capital, labour and technology. IT investment, as a capital good, can affect overall capital deepening (i.e., capital per unit of labour) and/or substitute IT capital with non-IT capital stock. A substitution between factor inputs represents movement along the production function and could raise the output level along a given production possibilities frontier.

The general purpose technology nature of IT and its impact on productivity has now been well-documented (Lipsey, Carlaw, & Bekar, 2006). This means that positive returns to IT investment require investment in complementary assets. Therefore, return from IT investment can only be generated fully in the long run (Ceccobelli, Gitto, & Mancuso, 2012). The capital deepening resulting from the investment of IT is referred to as an important driver of economic growth and productivity in a rich body of literature (Ahmad, Schreyer, & Wölfl, 2004; Jorgenson & Stiroh, 2000).

The particular nature of IT capital vis-à-vis other forms of capital reflects that unlike the latter, which have a diminishing marginal product, IT investment can exhibit positive externalities so that they show increasing marginal products in the aggregate. This stimulates increasing social returns which in turn leads to sustained positive growth rates as envisaged by the endogenous growth theory (Romer, 1991).

Empirical evidence revealed a strong contribution of IT capital deepening to GDP growth in advanced countries over the period 1995–2001 as compared to the historical perspective (Ahmad et al., 2004; Colecchia & Schreyer, 2002). However, the results from the macro level studies are at best mixed. In a seminal study, Jorgenson and Stiroh (1999) applied growth accounting framework and found that about 5% of the output growth in the US was attributed to computer-related capital services for 1990–1996 as compared to about 4% for 1973–1990 and about a 0.6% contribution prior to 1973. Parham et al. (2001) and Parham (2004) examined the case for Australia and found strong evidence of IT-led multifactor productivity and economic growth in the 1990s. Nonetheless, the contribution from IT capital on productivity has come at the expense of the use of other capital – reflecting a modest overall contribution of total capital (Gretton, Gali, & Parham, 2002; Parham et al., 2001). Quiggin (2001, 2006), however, opposed the 'new economy' viewpoint and 'productivity surge' in Australia in the 1990s.

Colecchia and Schreyer (2002) examined the case for nine OECD countries and found that the contribution of IT capital accumulation on output growth varied between 3% and 9% during 1990s as compared to 2% and 5% during 1970s and 1980s, respectively. Gordon (2000), however, noted that much of the productivity resurgence in the 1990s in the US was aided by the favourable economic conditions rather than the contribution of IT. In a relatively recent study Jorgenson, Ho, and Stiroh (2008) found that the role of IT on economic performance was less important in the post-2000 period for the same country.

Datta and Agarwal (2004) applied the cross-country growth framework for a panel of 22 OECD countries for the period of 1980–1992 and found a strong and positive relationship between telecommunication infrastructure and economic growth. They, however, found evidence of diminishing marginal returns of telecommunication investment at a later level of economic development. Therefore, the role of IT capital deepening on economic growth remains an evolving research issue.

Levendis and Lee (2012) focused on the endogeneity issue in the context of the direction of causation between telecommunication investment and economic growth. Motivated by the concept of endogenous growth theory, they argued that 'diminishing marginal productivity might be present at the micro level, while positive externalities may induce increasing returns at the aggregate level' (p. 2). It is therefore appropriate to apply simultaneous equations modelling to explore the causality between telecommunication investment and economic growth and productivity as each of the variables affect each other in an endogenous setting. Given the context, most of the earlier studies using a single equation model would provide misleading results. Recent studies using simultaneous equations modelling include those of Wolde-Rufael (2007) which found evidence of a bi-directional causality between telecommunication investment and economic growth in the US over the period 1947–1996. Nonetheless, a major shortcoming prevails in most of the earlier studies from the use of bivariate models (e.g., Beil, Ford, & Jackson, 2005; Cronin, Colleran, Herbert, & Lewitzky, 1993; Cronin, Parker, Colleran, & Gold, 1991; Dutta, 2001; Lam & Shiu, 2010; Shiu & Lam, 2008; Tranos, 2012; Wolde-Rufael, 2007). Omitted-variable bias is particularly an issue when investigating the causal relationship using a bivariate model because it ignores the additional channels through which the variables are interlinked (Shahiduzzaman & Alam, 2012). Therefore, a multivariate approach that reduces the potential of omitted variable biases is preferable.[1]

We overcome the gaps in the literature by estimating a production function to examine the role of IT capital on economic growth and also by employing a simultaneous equation modelling to explore the causality between IT capital deepening on labour productivity and technical progress and vice versa. We estimated the shift parameter (i.e., technical progress) of the production function and the relative roles of IT and non-IT capital stock and factor inputs over the period of time. The study is more comprehensive than the existing studies in that it captures both production function modelling and multivariate causality analysis using Australian data for the last four decades and until 2011.

4. Methodology

4.1. Framework

In order to measure the impact of IT capital on economic growth and productivity, the Cobb–Douglas production function framework is utilised (Cobb & Douglas, 1928). The Cobb–Douglas production function is a particular functional form that describes the relationship between production input and the possible maximum output under a given technology. It is based on the micro-foundation that the production processes are well described by a linear homogenous function of the first degree with diminishing marginal returns to either factor of production. The influential work by Solow (1957) and the growing focus of technical change have brought the Cobb–Douglas production function to the forefront as a measurement framework of the economic analysis of productivity and growth. Over the period of time, the specification has been used ubiquitously to estimate the aggregate production function (Felipe & Adams, 2005). Economic application of the Cobb–Douglas production function is based on the assumption that the income shares of labour and capital remain constant over time, which might not be true in reality, especially, in the context of using macro data (Griliches & Mairesse, 1995). However, this is a difficult task to find a simple mathematical formulation that captures the whole array of complex interaction that characterises a real economy. Miller (2008) examines the major strengths and weaknesses of the Cobb–Douglas and Constant Elasticity of Substitution (CES) functional forms and finds that, despite some limitations, the Cobb–Douglas shows seemingly better empirical fit across many data sets. In a relatively early study, Douglas (1976) found the evidence of Cobb–Douglas form of production function for the Australian manufacturing industries for several years in the 1950s and 1960s.

Let us begin with an aggregate production function that takes the following form:

$$Y = F(K, \ L; \ t) \tag{1}$$

In (1) Y represents output and K and L represent capital and labour inputs respectively. The variable t represents time factor. The conventional growth accounting framework describes output growth in an economy as being generated through

[1] A separate stem of literature has made the use of a non-parametric multivariate approach. The advantage of the non-parametric approach is that, unlike parametric approach of using production function, it does not impose any particular constraint in the form of production function. Non-parametric approach has widely been applied to decompose TFP growth, cross country growth and convergence literature. Interested readers can consult Ceccobelli et al. (2012), for a review and application of the non-parametric method in the IT-growth––productivity literature.

a change in inputs and through the change of technology, popularly known as 'technical change'. A change in inputs, such as capital and labour, represents a movement along a given production function, while technical change leads to any kind of shift in the production function (Jorgenson & Stiroh, 1999; Solow, 1957).

Assuming that the production function (1) satisfies a certain economic neutrality condition, i.e., the marginal rate of substitution between capital and labour remains untouched, Eq. (1) can be written as

$$Y = A(t)f(K, L) \tag{1.1}$$

In (1.1) $A(t)$ describes the cumulative effects of technical change, i.e., the shifts of the production function over time. Note that the K in (1) includes both IT and non-IT capital stock. If we consider that IT and non-IT capitals are separate inputs of production, the production function could be specified as follows, taking natural logarithm (ln):

$$\ln Y = \zeta + \phi \ln A + \alpha \ln K_{\text{nit}} + \beta \ln K_{\text{it}} + \gamma \ln L + \varepsilon t \tag{1.2}$$

where, K_{nit} and K_{it} refer to non-IT and IT capital respectively. The parameters α, β and γ are the output elasticity of the relevant factor inputs and ζ and εt are the constant and error terms respectively. The shift factor A is popularly known as *Solow Residual* and the mathematical formulation to compute it at each point of time is described in Solow (1957).

Eq. (1.2) can be expressed in terms of output per unit of labour (i.e., labour productivity)

$$\ln y = \zeta + \phi \ln A + \alpha \ln k_{\text{nit}} + \beta \ln k_{\text{it}} + \varepsilon t \tag{1.3}$$

Given that $\alpha+\beta+\gamma=1$. In Eq. (1.3) $k_{\text{nit}}=K_{\text{nit}}/L$ and $k_{\text{it}}=K_{\text{it}}/L$, where the variables k_{nit} and k_{it} represent capital deepening in terms of non-IT capital and IT capital respectively.

The above formulations can be used to estimate of the role of IT capital on output growth and labour productivity. In addition, a vector autoregressive (VAR) model can be formulated to examine the causality among the variables, especially between IT capital deepening and technical progress. We applied the TY approach, which uses a VAR model in level, to investigate causality among IT and non-IT capital deepening, labour productivity and technical change. The TY approach involves estimation of an augmented VAR (k+*dmax*) model in which k is the optimal lag length in the original VAR system and *dmax* is the maximum order of the integration of the variables. The procedure uses a modified Wald (*mWald*) test for cases with zero restrictions on the parameters of the first k lags. This statistic follows an asymptotic chi-squared distribution with k degrees of freedom in the limit when a VAR (k+*dmax*) is estimated.

4.2. Variables and data

The variable Y represents gross value-added using chain volume measures (in Aus$ million, reference year 2009–2010) and L represents labour services (hours worked). K_{nit} and K_{it} denote the chain volume measure of non-IT and IT net capital stocks, respectively. The data for Y, L and income share of capital are collected from Australian Bureau of Statistics (ABS) cat. no. 5260.0, while data for net capital stocks (both IT and non-IT) are collected from ABS cat. no. 5204.0, both available online. IT capital stock consists of three categories of capital stocks – computers and peripherals, computer software and electrical and electronic equipment. This categorisation is based on ABS's definition of Information Technology net capital stock (Table 69, Cat no. 5204). The capital series needs to be adjusted for utilisation. Because time series data for capital utilisation in Australia are not available for the long time series, following Solow (1957), employment rate is used as a proxy for capital utilisation. Data for the unemployment rates is collected online from ABS (cat. no. 1364.0). All variables are indexed as 2009–2010 = 100 for the estimation purpose. Income share of capital is collected online from ABS (cat. no. 5260.0). The sample covers 1975–2011 and represents data for the Australian market sector (16 industries of the economy). Table 1 reports the description statistics of the variables employed in this study. As shown in the table, that output grew at an average rate of 3.1% as compared to the average growth rate of IT capital of 10.2% and non-IT capital of 3.5% during 1975–2011. During the sample period, average labour productivity growth was 1.2% as compared to 8% for the IT capital and 1.6% for the non-IT capital stocks.

Table 1
Descriptive statistics of the variables.

	Y Billion A$	K_{it} Billion A$	K_{nit} Billion A$	L Thousand	y	k_{it}	k_{nit}
Initial value (1975)	427.9	3.9	1172.9	6199.8	52.6	0.4	117.3
Ending value (2011)	1318.6	131.0	4058.6	12084.7	109.1	10.8	335.8
Av. growth rate (1975–2011)	3.1	10.2	3.5	1.9	1.2	8.0	1.6
Mean	793.4	32.6	2356.3	8749.1	87.6	3.1	259.5
Median	718.7	16.9	2244.5	8615.1	82.4	1.9	258.4
Observations	38	38	38	38	38	38	38

5. Results

5.1. Shift in production function

This subsection presents the estimation of the technical change or shift factor of the production function using the methodology described above. Panel I in Fig. 3 presents the growth of A ($\Delta A/A$) for the period 1975–2011. As shown in the figure, technical change experienced substantial ups and downs until the mid-1980s before stabilizing to a relatively higher average level in the 1990s. Unlike the recession in the early 1980s, the growth of technical change remained relatively stable during the period of economic recession in the early 1990s. The average rate of growth of technical change during 1975–1990 was only 0.6% as compared to 1.5% during 1990–2000. This indicates that technical change improved by an average of about 100 basis points in the 1990s. Nonetheless, the technical change has significantly slowed down in recent years, especially during the second half of the 2000s and also in 2011. These estimates are very much consistent with the ABS estimates of multifactor productivity growth as shown in Fig. 1. Panel II in Fig. 3 shows the shift in the production function over the period 1975–2011 due to technical change. The values are derived, by arbitrarily setting $A\,(1975)=1$ and then using $A(t+1)=A(t)(1+\Delta A(t)/A(t))$ to construct the series successively. The $A(t)$ series shows that technical progress is strongly upward since the late 1980s to the early 2000s. Therefore, an upward shift of the production function due to technical change is clearly evident. The period of the 1990s can therefore be referred to as the period of technical progress in the Australian economy. The curve, however, shifted downward in recent years, but still remains at a high level as compared to the historical average.

Panel I in Fig. 4 shows the scattered plot of the $\Delta A/A$ or $\Delta F/F$ against $\Delta K/L$. As seen in the figure, no sign of correlation can be found between these two variables postulating the evidence that overall technical progress with respect to factor inputs such as capital and labour remained neutral over the period of time. The result is similar, if we only consider the non-IT capital stock (Fig. 4, Panel II). A significant difference can, however, be observed once we plot $\Delta A/A$ against Δk_{it} (Fig. 5). As can be seen in Fig. 5, a clear divergence of the relationship between technical change and change in IT capital deepening occurred in the recent years as compared to the 1980s and the 1990s. Clearly, there seems to be a structural shift in the relationship between technical change and IT capital deepening in recent years as the scattered plots for the second part of the 2000s are shown to be isolated from the preceding decades (the oval in Fig. 5). The downward shift of the degree of correlation between these two variables might indicate a possible fall of IT productivity in recent years.

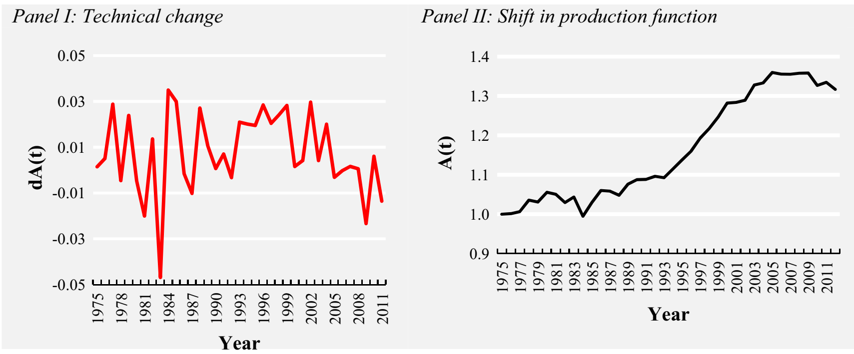

Fig. 3. Technical change in Australian market sector, 1975–2011.

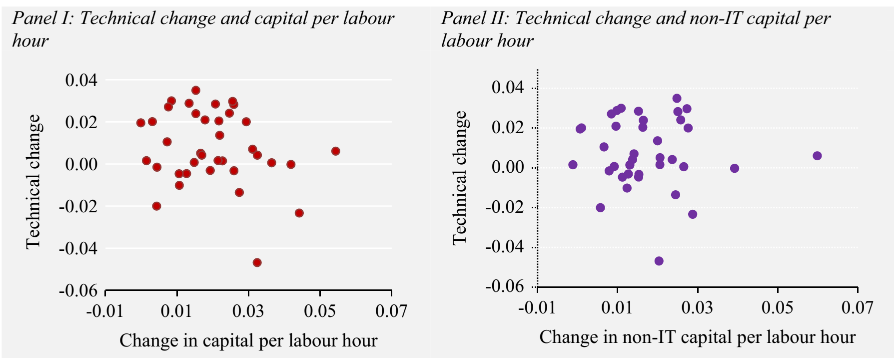

Fig. 4. Correlation between technical change and capital (total and non-IT) per labour hour.

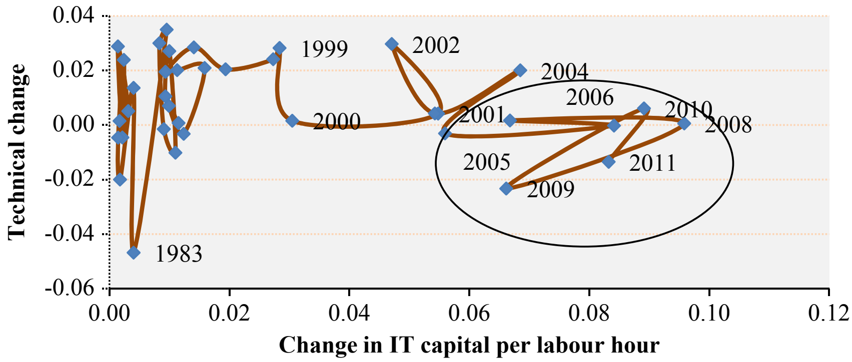

Fig. 5. Technical change and IT capital per labour hour.

Table 2
Single-equation estimation of the production functions.

Dependent variable Y	Sample		
Independent variables	1975–90	1991–2000	2001–11
L	0.54[a] (0.04)	0.52[a] (0.04)	0.53[a] (0.04)
K_{it}	0.001 (0.01)	0.08[a] (0.02)	0.07 (0.04)
K_{nit}	0.47[a] (0.03)	0.19[a] (0.06)	0.34[a] (0.08)
A	0.92[a0] (0.06)	1.19[a] (0.06)	0.79[a] (0.09)
Constant	−0.39[c] (0.19)	0.59[a] (0.15)	0.06 (0.34)
R^2	0.99	0.99	0.99
DW	1.85	1.82	1.86
Breusch–Godfrey test	Prob. values: $F(1,11)=0.90$, χ^2 $(1)=0.87$	Prob. values: $F(1,11)=0.89$, χ^2 $(1)=0.81$	Prob. values: $F(1,11)=0.94$, χ^2 $(1)=0.91$

Note—Figures in parentheses show the robust standard error. The residual properties of the estimated models are examined through the Breusch–Godfrey autocorrelation LM test.
[a] Denotes significance levels at 1%.
[c] Denote significance levels at 10%.

5.2. Regression analysis

Table 2 reports the estimation of Eq. (1.2) that separates total capital into IT and non-IT components for 1975–2011, and breaks it into three sub-periods (1975–90, 1991–2000 and 2001–11).[2] For 1975–90 the output elasticity of labour and non-IT capital is 54% and 47% respectively, with little contribution from the shift parameter ($A<1$)[3]. There is no significant effect of IT capital on output before the 1990s. However, the output elasticity of IT capital stood at 8% for 1991–2000, while the output elasticity of non-IT capital experienced a major decline and the contribution of labour remained relatively unchanged. During the period, a major contribution of GDP growth came from technical progress ($A>1$). Nonetheless, the output elasticity of IT capital became insignificant during 2001–2011 and the contribution of non-IT capital improved again, while the contribution from technical progress deteriorated. Comparing these results, it appears that the contribution of IT on output growth has declined significantly (p-value 0.12) during the 2000s as compared to the preceding decade.

Table 3 reports the estimation of labour productivity Eq. (1.3), which assumes constant returns to scale of factor inputs. Similar to the results presented in Table 2, the contribution of IT capital deepening becomes insignificant for 1975–1990. However, IT capital deepening has demonstrates a significant and large positive impact ($\beta=0.11$) on labour productivity for 1991–1999[4]. However, the contribution of IT capital deepening deteriorates in the 1990s as compared to the preceding decade. The contribution of IT capital deepening on labour productivity, however, has declined significantly during 2001–2011. This means that the contribution of IT capital deepening on labour productivity reached its peak in the 1990s from a very low level in the 1970s and again experienced a significant deterioration in the 2000s. Therefore, the role of IT capital deepening on labour productivity shows an inverted U-shaped trajectory over the period 1975–2011 in Australia.

[2] The choice of the sub-samples in this study is based on the results from previous literature. Existing studies documented that the contribution of IT capital was significantly higher in the 1990s as compared to the preceding periods (Colecchia & Schreyer, 2002; Parham et al., 2001). We therefore opted to divide the sample in such a way that it can capture the 1990s episode separately.

[3] The value of A is taken as 1 for 1974 to derive the subsequent values as described earlier.

[4] The sample of 1991–1999 is chosen due to the possible structural break in labour productivity data in 2000. Not only does the visual plot of the first difference of the lny shows the structural break in 2000, but also the estimation results distort significantly if the year 2000 is included in the models. Detailed results on this can be obtained from the authors upon request. The presence of the structural break in 2000 in the productivity series in Australia is consistent with those of Parham (2002b, 2005b).

Table 3
Estimation results – labour productivity.

Dependent variable y	Samples		
Independent variables	1975–90	1991–99	2001–11
k_{it}	0.004(0.01)	0.11[a](0.03)	0.04[b](0.02)
k_{nit}	0.47[a](0.02)	0.30[b](0.09)	0.39[a](0.05)
A	0.92[a](0.05)	0.86[a](0.08)	0.84[a](0.05)
Constant	−0.34[a](0.01)	−0.19[a](0.04)	−0.24(0.01)
R^2	0.99	0.99	0.99
DW	1.82	1.90	1.75
Breusch–Godfrey serial correlation LM test	Prob. values: $F(1,11)=0.93$, χ^2 $(1)=0.91$	Prob. values: $F(1,11)=0.98$, χ^2 $(1)=0.97$	Prob. values: $F(1,11)=0.88$, χ^2 $(1)=0.84$

Note—Figures in parentheses show the robust standard error. The residual properties of the estimated models are examined through the Breusch–Godfrey autocorrelation LM test.
[a] Denotes significance levels at 1%.
[b] Denotes significance levels at 5%.

Table 4
TY causality tests.

Null hypothesis	Modified Wald statistics	p-Value	Sum of lagged coefficients
k_{it} Does not Granger-cause y	24.23	0.00	0.03
y Does not Granger-cause k_{it}	4.41	0.22	−0.05
k_{it} Does not Granger-cause A	24.77	0.00	0.07
A does not Granger-cause k_{it}	5.51	0.14	0.02
k_{nit} Does not Granger-cause y	30.25	0.00	−1.89
y Does not Granger-cause k_{nit}	2.37	0.50	−0.61
k_{nit} Does not Granger-cause A	24.77	0.00	0.07
A does not Granger-cause k_{nit}	3.09	0.38	0.38
k_{it} Does not Granger-cause k_{nit}	3.05	0.38	−0.07
k_{nit} Does not Granger-cause k_{it}	14.12	0.00	−0.69

Notes—Results are obtained through seemingly unrelated regression (SUR) estimations. The sum of lagged coefficients is the summation of lags, excluding the lagged coefficients with the highest order (see, for example, Squalli, 2007).

The impact of technical progress on labour productivity appears to be less than proportional along with a slightly declining trend over the period of time. However, the sum of the coefficients of IT and non-IT capital deepening and technical progress on labour productivity is consistently greater than 1 indicating an increasing productivity effect during the sample period.

5.3. Granger causality

Table 4 reports the results of the Granger causality test for the labour productivity Eq. (1.3) using the TY procedure. The optimal lag length k for the TY procedure is set to 3 based on the sequential modified LR criteria and $dmax$ is set to 1 based on the unit root tests.[5] The TY approach is to be implemented through the seemingly unrelated regression (SUR) procedures (Rambaldi & Doran, 1996).

The TY test supports the view that IT capital deepening (k_{it}) Granger-causes both labour productivity (y) and technical progress (A). However, the converse is not true. The sign of the sum of lagged coefficients indicates the positive causal effects of k_{it} on y *and* A. The results, therefore, indicate that a positive unidirectional causality exists from k_{it} *to* y and A. The presence of unidirectional causality is also found from non-IT capital deepening (k_{nit}) and y, but the sign of the sum of lagged coefficients indicates the negative causality running from k_{nit} to y. This is consistent with the observed data in that the capital productivity has fallen over time (Dolman, 2009). Nonetheless, like k_{it}, k_{nit} placed a positive causal effect in stimulating technical progress and the sum of lagged coefficients are remarkably the same (0.07) in both cases. Therefore, both IT and non-IT capital deepening have caused the technical progress to take place in the Australian economy during 1975–2011 at a similar extent. The causality results further indicate a unidirectional negative causality from k_{nit} to k_{it} but not in the opposite direction.

[5] Results are not reported here to save space but can be obtained from the authors upon request. The unit root tests implemented here are Augmented Dickey–Fuller (Dickey & Fuller, 1979, 1981), Phillips–Perron (Phillips & Perron, 1988) and Kwiatkowski–Phillips–Schmidt–Shin (Kwiatkowski, Phillips, Schmidt, & Shin, 1992). Tests results indicate a first difference stationarity for all four series.

6. Conclusion and policy implications

In this paper we have investigated the role of IT capital on economic growth, productivity and technical progress in the context of changing economic environment in Australia during the last four decades. This estimates a production function to examine the role of IT capital on economic growth and also employs simultaneous equation modelling to explore the causality between IT capital deepening on labour productivity and technical progress. As opposed to bulk of the existing literature using bivariate models and single equation modelling, this study uses multivariate and simultaneous equations modelling to explore the Granger causality to shed light on the relationship between capital deepening and technical progress. By doing so, the methodological framework used in this paper overcomes the problems of omitted variable bias and addresses the endogeneity issue. Moreover, it makes use of recent data along with providing adequate understanding on longer term perspective for Australia. This study is more comprehensive than earlier research in that it examines both the contribution of IT capital on output and labour productivity, and the Granger causality between the variables using data for about four decades in Australia.

The estimation results in the study confirm the significant role of IT capital on economic growth and productivity during the 1990s as found in the earlier studies (Parham, 2002a, 2004). However, the contribution of non-IT capital on both growth and productivity has slowed during the recent period. We also found evidence of possible fall of IT capital productivity in recent years. The overall productivity downturn of the Australian economy in recent years might therefore be linked to, among other factors, the slump of IT capital productivity. Overall, technical change played a positive role on economic growth in the Australian economy for last four decades. The contribution of technical change on economic output was highest in the 1990s but has slowed down significantly in the 2000s.

Over the longer term, evidence of unidirectional causality was found running from IT capital deepening to labour productivity and technical progress. The evidence of unidirectional causality from IT capital deepening to labour productivity and technical progress indicates that any external shock to IT investment can readily be transmitted to labour productivity and technical progress. This suggests that increases in IT capital deepening could accelerate technical progress and labour productivity and, thereby, economic growth. Similarly, decreases in IT investment will slow the pace of economic growth. Nonetheless, the possible decline of IT productivity may decay the benefits from greater IT investment – this is an issue that needs to be explored further from the empirical and policy perspectives.

The causality results, however, indicate that the contribution of IT capital deepening on labour productivity happened at no cost of non-IT capital, rather the latter put a constraint to cause the former. As seen from production function estimates, the contribution of non-IT capital stock was lower in 1990s as compared to the preceding periods. In 2000s, the contribution of non-IT capital has shown a sign of recovery, while the contribution of IT capital on both economic growth and productivity has shown a sluggish picture. The dismal picture of the contribution of IT capital on growth and productivity shown in this study is of particular concern for the Australian economy in the context of future improvements of IT-related investments.

Obviously, the productivity performance of IT capital varies widely across economic sectors, industries and firms. To what extent IT productivity gains vary across the units of the economy, what are the determining factors that can explain the divergence and how these can affect the economy-wide performance are emerging research issues. As a favourable policy environment is a prerequisite to yield the IT productivity gains, it is important to identify particular areas where policy interventions are required to boost IT capability. It is argued that the benefits of IT productivity gains could be relatively low at a certain stage when businesses are exposed to the human capital development and organisational changes that do not readily translate to gains in productivity (Van Ark & Inklaar, 2005). Over time, the effects of these changes become evident and a boost in productivity is experienced again. The critical question is that whether such organisational changes are in place to generate IT-related investment, innovation and diffusion in the coming years. The production function framework used in the study is unable to capture these issues. The way of measuring productivity as residual has also long been criticised (Hartley, 2000; Jorgenson & Griliches, 1967). However, productivity measurement is not an exact science and there are alternative methods of measuring it (Atkinson, Cornwell, & Honerkamp, 2003; Nordhaus, 2001). Accordingly, the results from this study may not be invariant across different methods of estimating productivity. These issues remain open for further research in the future.

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