Contribution of ICT Diffusion to Labour Productivity Growth: The United States, Canada, the Eurozone, and the United Kingdom, 1970-2013

Gilbert Cette, Christian Clerc and Lea Bresson
Banque de France, Université Aix-Marseille, Centre National de la Recherche Scientifique et École des Hautes Études en Sciences Sociales[1]

ABSTRACT

This study measures and compares the trends in ICT diffusion and the contribution of ICT to labour productivity growth in the United States, Canada, the Eurozone, and the United Kingdom from 1970 to 2013. There are three main results: i) after a long period of sustained growth, ICT diffusion, as measured by the share of ICT capital stock to GDP expressed in current prices, has stabilized since 2000 in all four areas; ii) this stabilization happened at different levels, significantly higher in the United States than elsewhere; and iii) in all four jurisdictions, the contribution of ICT to labour productivity growth rose significantly in 1994-2004 compared to 1974-1994. Since 2004, the contribution of ICT to labour productivity growth has fallen off considerably. It only remains positive as a result of the continued advances in ICT performance as proxied by the continued fall in ICT prices. Unfortunately, the pace of improvement also appears to be rapidly decreasing.

AMPLE EMPIRICAL LITERATURE HAS been dedicated to the analysis of the diffusion of information and communication technologies (ICT) and the contribution of ICT to economic growth.[2] This study characterizes and compares the evolution of ICT diffusion and the contribution of ICT to labour productivity growth. It shows that ICT diffusion continuously increased until the 2000s and then stabilized or slightly declined. As in Cette and Lopez (2012), we demonstrate that ICT diffusion, as a factor of production in advanced countries, stabilized in the beginning of the 2000s at a higher level in the United States than in the other countries studied. We also found that the contribution of ICT to labour productivity was higher in the United States. Moreover, our results are consistent with those of Byrne *et al.* (2013) showing that the contribution of ICT to labour productivity growth sharply fell in the United States starting in the middle of the 2000s before the most recent crisis.

1 The authors would like to thank Andrew Sharpe and two anonymous referees for comments. The authors would also like to thank Dirk Pilat, Belen Zinni and Anita Woelf of the OECD for having provided the ICT investment data. Email: gilbert.cette@banque-france.fr.

2 See Jorgenson (2001), Jorgenson *et al.* (2006), and Byrne *et al.* (2013) for the United States; and Schreyer (2000), Colecchia and Schreyer (2001), Pilat and Lee (2001), van Ark *et al.* (2008), Cette *et al.* (2009), Timmer *et al.* (2011), and Cette and Lopez (2012) for different advanced countries.

In order to provide a long-term perspective, this study covers the 1970–2013 period and focuses on the total economy of each country, not only the business sector. To perform such an analysis, we built an ICT capital stock series with OECD data.

In theory, the contribution of ICT to labour productivity growth passes through two channels. First, the use of ICT as a factor of production increases capital intensity which increases labour productivity. Second, the ICT-producing sector has higher levels of productivity, on average, than other economic sectors; therefore as the relative important of this sector increases, labour productivity increases. Our analysis is linked to the first channel.

Section 1 presents the data and the methodology for evaluating the contribution of ICT to labour productivity growth. Sections 2 and 3 successively describe the diffusion of ICT as a factor of production and show the contribution of these technologies to labour productivity growth. Section 4 concludes.

Data and Methodology

The ICT investment data were provided by the OECD for the total economy for each of the three ICT components (hardware, software, and communications equipment) for the G7 (except Japan), three other large European countries (Spain, Belgium, and the Netherlands), and a Scandinavian country (Finland). A 'Eurozone' is reconstructed by aggregating the data of Germany, Belgium, France, Italy, Spain, the Netherlands, and Finland. These countries represented 84 per cent of GDP in the Eurozone in 2012. The data we used were available for the period from 1960 through 2012 (2011 for the United Kingdom), and after a number of corrections and backward extrapolations, we made the data available for the 1950-2012 period.

The capital stock in volume and value terms is constructed for each of the three ICT components using the perpetual inventory method[3] while assuming a constant annual depreciation rate of 30 per for hardware and software and 15 per cent for communications equipment, as in Cette *et al.* (2009). The total ICT capital stock is calculated, in value and volume, by aggregating the capital stock of each component.

The data on GDP in current prices and the GDP deflator come from Eurostat and the OECD. The investment price indices are built, for each country and ICT component, from the US Bureau of Economic Analysis (BEA) National Account Data. BEA integrates technological advances into ICT prices series via hedonic methods. For the other countries, we assume, as proposed by Schreyer (2000), that the relative price ratio of investment in each of the ICT components to GDP is the same as that of the United States. Country-specific ICT price indices from each country were not used due to the inherent difficulty of making international comparison. Instead, by using the BEA methodology for the calculation of non-US ICT deflators we can make international comparisons and incorporate ICT quality improvements simultaneously. All of the price indices and deflators have a base year of 2005 by convention.

The contribution of ICT capital to labour productivity growth was estimated using a growth accounting approach. This is detailed in Box 1.

3 For each of the three ICT components indexed by j, the capital stock (in value or volume) at the end of year t, $K_{j,t}$, is constructed using the relationship: $K_{j,t} = I_{j,t} + (1-\delta_j)K_{j,t-1}$ where $I_{j,t}$ corresponds to investment in component j during the year t, and δ_j refers to the constant annual depreciation rate specific to component j.

Box 1

Methodology for Estimating the Contribution of ICT to Labour Productivity Growth

The contribution of ICT to labour productivity growth is estimated for each of the three ICT components by applying the growth accounting methodology suggested by Solow (1957).

For each ICT component (the index is excluded for notational purposes), the contribution of capital to labour productivity growth in year t, noted as CO_t, is estimated through the following relation:

$$CO_t = \alpha_t (\Delta k_{t-1} - \Delta n_t - \Delta h_t)$$

where k_{t-1} corresponds to the capital in place at the end of year $t-1$, n_t refers to total employment in year t, and h_t designates the average annual hours worked per person per year t. The notation of the variables in lower case corresponds to their natural log ($x_t = ln(X_t)$), and the growth rate of a variable is approximated by the variation of its logarithm. The Δ symbol refers to the change of a variable ($\Delta X_t = X_t - X_{t-1}$).

The coefficient $\alpha_{T,t}$ is the Tornquist index of the coefficient α_t:

$$\alpha_{T,t} = (\alpha_t + \alpha_{t-1})/2$$

The coefficient α_t corresponds to the share of capital income (remember that this is calculated for each ICT component) in GDP:

$$\alpha_{T,t} = (C_t K_{t-1})/(PQ_t Q_t)$$

where C_t corresponds to the user cost of capital, K refers to the capital stock in volume, PQ corresponds to the GDP deflator, and Q refers to GDP in volume.

The user cost of capital C is calculated eusing the relationship proposed by Jorgenson (1963):

$$C_t = P_t (i_t + \delta + \Delta p_t)$$

where P corresponds to the investment price of the ICT component, i refers to the nominal interest rate, and δ designates the assumed invariant depreciation rate of the ICT component.

In this study, we used the 10 year government bond interest rates for the nominal interest rate.

The Diffusion of ICT

The diffusion of ICT is proxied by the capital coefficient, defined as the ratio of ICT capital stock to GDP. This indicator can be constructed in value or in volume terms.

Following a balanced growth path, once ICT diffusion reaches maturity, we expect stability in the ICT capital coefficient in value. In the past few decades, we observed a continuous drop in the relative price of ICT which has significantly contributed to a fall in the relative price of investment goods (Table 1). This decrease in price means that the ICT capital coefficient in volume has clearly grown much faster than its expression in value.

The drop in the relative price of ICT rapidly slows starting in the middle of the 2000s before the beginning of the most recent crisis. This slowdown, which has provoked a still inconclusive debate in the economics literature, receives diverse interpretations (see Cette, 2014, for a summary). One theory, developed by Gordon (2012, 2013), shows how the slowdown in price decreases can result from a gradual exhaustion of Moore's Law due to the slower pace of technological advances in semiconductor chips. In addition to this factor, measurement difficulties in national accounts may also explain this phenomenon (Cette, 2014, Aizcorbe *et al.*, 2008, or Byrne *et al.*, 2013).

Table 1

Trends in the Fixed Investment Prices Relative to the GDP Deflator in the United States, 1959-2012

(average annual rate of change, per cent)

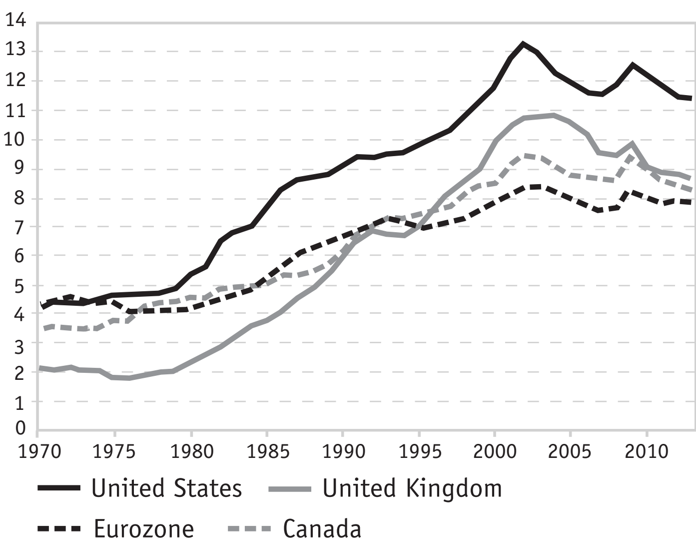
	1959-2012	1959-1974	1974-1995	1995-2004	2004-2012
Non-Residential Fixed Investment	-2.27	-1.85	-1.88	-4.11	-2.02
ICT	-7.16	-6.02	-8.26	-8.95	-4.46
Hardware (Computers)	-18.56	-22.71	-18.45	-19.89	-9.93
Software	-4.23	-4.45	-5.35	-2.72	-2.22
Communication Equipment	-3.33	-0.86	-2.70	-6.52	-5.29

Source: Authors' calculations from BEA original data.

Chart 1

Trends in the ICT Capital Coefficient, 1970-2013

(Ratio of ICT capital stock to GDP in current prices, per cent)



Source: Authors' calculations.

After the rather stable decade of the 1970s, the ICT capital coefficient in value rose in the 1980s and 1990s in the United States, Canada, the Eurozone, and the United Kingdom (Chart 1). This rise implies a growth in ICT diffusion which is linked to an increase in the use of these productive technologies. The ICT coefficient achieved a maximum at the beginning of the 2000s and then stabilized in the Eurozone, decreasing slightly in the United States and Canada, and declining more in the United Kingdom. The peak at the beginning of the 2000s signifies a spurred investment effort associated with the fear of Y2K.

The stability of the nominal ICT capital coefficient since the beginning of the 2000s has already been observed by Cette and Lopez (2012). Our study confirms this result and shows that the stagnation persisted during the crisis. The diffusion of ICT as a factor of production appears to have been stabilized for more than a decade.

The stabilization of the ICT capital coefficient in current prices is at different levels depending on the country. ICT diffusion in the United States settled at a higher level than in the Eurozone, the United Kingdom and Canada. The lag of ICT diffusion is considerable. By 2012, the United States had an ICT capital coefficient that was 30 per cent, 27 per cent, and 25 per cent higher than the Eurozone, Canada, and the United Kingdom, respectively. For Canada, this corresponds to a gap of 40 per cent in ICT investment per worker. Our results are completely consistent with those of Rai and Sharpe (2013).[4] Furthermore, earlier analyses support this hierarchy of ICT diffusion.[5]

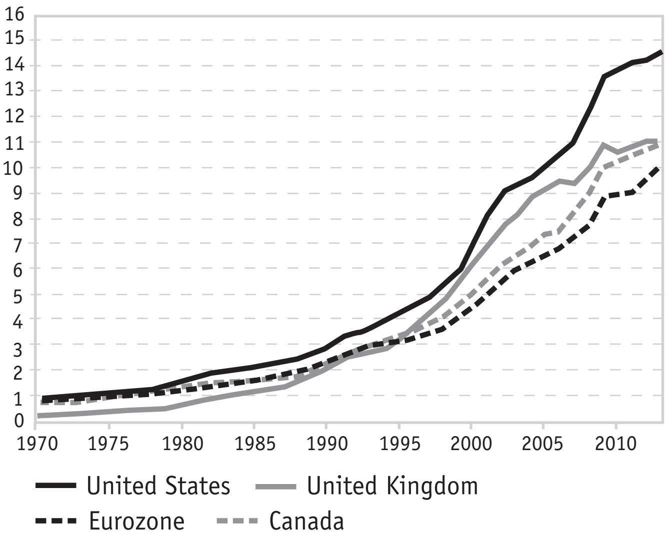
Numerous studies provide explanations for these international differences in ICT diffusion, including the level of post-secondary education among the working age population as well as labour and product market rigidities. For example, an efficient use of ICT requires a higher degree of skilled labour than the use of other technologies. The required reorganization of the firm for effective ICT adoption can be constrained by strict labour market regulations. Moreover, low levels of competitive pressure resulting from product market regulations can reduce the incentive to exploit the most efficient production techniques. A large number of empirical analyses have confirmed the importance of these factors.[6] Quite simply, the United States benefits from the highest level of ICT diffusion because of a higher level of post-secondary education among the working age population and less restrictive product and labour market regulations.

The ICT capital coefficient in volume terms continuously increased over the entire period in all jurisdictions (Chart 2). This indicator follows the same hierarchy of ICT diffusion as the preceding indicator at current prices. By 2012, the United States has the highest diffusion, the Eurozone exhibits the lowest, and Canada and the United Kingdom sit at intermediary positions.

Chart 2

Trends in the ICT Capital Coefficient, 1970-2013

(Ratio of ICT capital stock to GDP in constant 2005 prices, per cent)



Source: Authors' calculations.

A decomposition of the evolution of the ICT capital coefficient in volume terms identifies the contributions of the changes of the ICT capital coefficient in current prices and of relative prices (ICT relative to GDP) to the observed trends.[7] More precisely, this decomposition yields a third component corresponding to cross effects from changes in the ICT capital coefficient in value and the relative prices. The decomposition starts after the first oil shock and covers three sub-periods

4 Rai and Sharpe (2013) demonstrate that the Canada-U.S. ICT investment gap is due to factors which affect software investment and measurement issues.

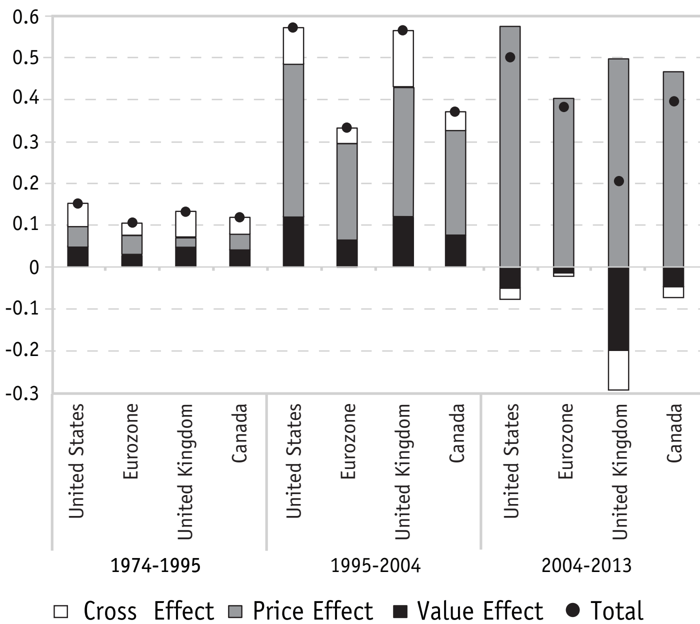
5 See Schreyer (2000), Colecchia and Shreyer (2001), Pilat and Lee (2001), van Ark *et al.* (2008), Timmer *et al.* (2011), and Cette and Lopez (2012).

6 See Aghion *et al.* (2009), Guerrieri *et al.* (2011) and Cette and Lopez (2012) who use country-level panel data, as well as Cette *et al.* (2013) who employ sectoral-level panel data.

7 The ICT capital coefficient in volume is written as K/Q, where K is the volume of ICT capital in place at the end of the period t-1 and Q is the volume of GDP in time t. It is defined by the following relationship: $K/Q = [(PK*K)/(PQ*Q)]*[PQ/PK]$, where PK corresponds to the price of ICT capital in place at the end of the period t-1 and PQ to the price of GDP in year t. The ratio $[(PK*K) / (PQ*Q)]$ corresponds to the ICT capital coefficient in value. Differentiating the preceding equation yields the decomposition formula used to estimate the evolutions of ICT capital in volume:

$$\Delta[K/Q] = \underbrace{[(PK*K)/(PQ*Q)]*\Delta[PQ/PK]}_{\text{Price effect}} + \underbrace{[PQ/PK]*\Delta[(PK*K)/(PQ*Q)]}_{\text{Value effect}} + \underbrace{\Delta[(PK*K)/(PQ*Q)]*\Delta[PQ/PK]}_{\text{Cross effect}}$$

Chart 3
Decomposition of the Evolution of the ICT Capital Coefficient in Volume
(percentage points per year)



Source: Authors' calculations.

which Byrne *et al.* (2013) also use: 1974–1995, 1995–2004 and 2004–2013.

During the 1974–1995 sub-period, each of the three components of the decomposition provides a relatively weak and uniform contribution to the rise in the ICT capital coefficient in constant prices (Chart 3). During the 1995–2004 sub-period, these three contributions are much larger, with the most significant clearly stemming from relative prices. Lastly, during the 2004–2013 sub-period, the contributions from the evolution of the ICT capital coefficient in value and from the cross effects become negligible in the Eurozone and negative in the United States, Canada, and the United Kingdom. The massive contribution from falling relative ICT prices explains the continued growth of ICT capital in volume.

Contribution of ICT Capital to Labour Productivity Growth

The contribution of ICT capital to labour productivity growth, which relates ICT capital to hours (ICT/hours), passes through two channels: first, the use of ICT as a factor of production, via an increase in the ICT capital intensity, and second, the production of the ICT-producing sector, due to a higher level of productivity, on average, than in other sectors. Here, we consider only the former. The estimation of the contribution of ICT to labour productivity growth, of which Box 1 details the methodology, is proposed for the three sub-periods previously mentioned starting after the first oil shock: 1975–1995, 1995–2004, and 2004–2013. It distinguishes the contributions of the three ICT components: hardware, software, and communications equipment.

The 1995–2004 sub-period shows the largest contribution of ICT to labour productivity growth (Chart 4). The literature frequently emphasizes the large increase in the contribution of ICT originating in the middle of the 1990s.[8] The increase is linked to the acceleration of the growth rate of ICT capital in volume which is connected to ICT capital in value and to the relative price of ICT with respect to GDP.

The decrease in the contribution of ICT to labour productivity growth over the last period has been discussed for the United States by Byrne *et al.* (2013). It has also been observed in Canada, the Eurozone, and the United Kingdom (Chart 4). This decline is explained by a slowdown in the growth of the volume of ICT capital which is linked to both the value of ICT capital (due to the slowing pace of ICT investment) and a smaller decrease in the relative price of ICT com-

8 See Jorgenson (2001), Jorgenson *et al.* (2006), or Byrne *et al.* (2013), for the United States, and Cette *et al.* (2009), van Ark *et al.* (2008), or Timmer *et al.* (2011), for different advanced countries.

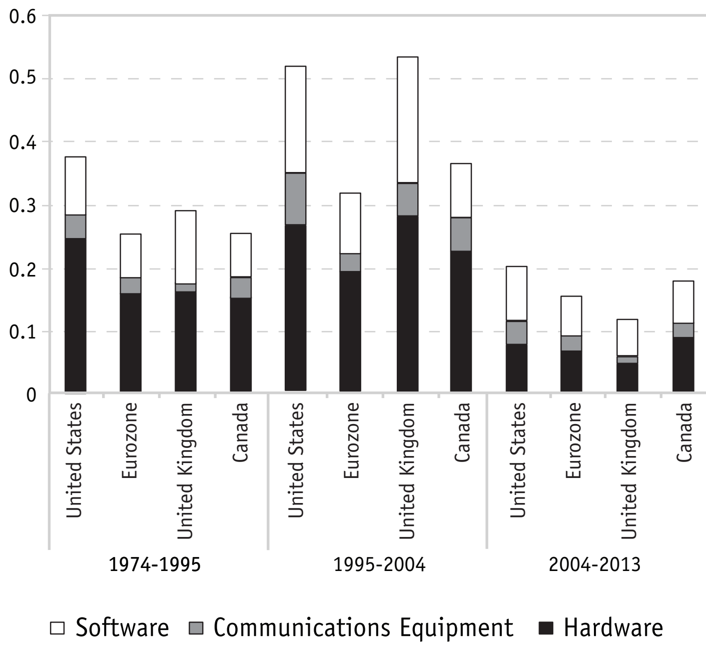
pared to GDP already mentioned above. This smaller decrease may signify, as noted earlier, a gradual exhaustion of the rate of improvements in ICT performance, although such a view is not agreed upon unanimously. Finally, we note that over the three sub-periods, the contribution of the communications equipment component is clearly less than the other two: hardware and software.

Conclusion

Three main results from the preceding analysis are obtained: i) after a long period of sustained growth, ICT capital as a factor of production stabilized in the beginning of the 2000s in the United States, Canada, the Eurozone, and the United Kingdom, and it slightly decreased starting in the middle of the 2000s; ii) this stabilization took place at different levels. It was significantly higher in the United States than in the Eurozone. Canada and the United Kingdom occupy an intermediary level; and iii) in the United States, Canada, the Eurozone, and the United Kingdom, the contribution of ICT to labour productivity growth significantly rose in 1995-2004 relative to 1974-1995. However, the contribution fell in 2004-2013. It only remains positive as a result of continued advances in ICT performance as proxied by falls in the relative price of ICT. These improvements also appear to be sharply decreasing.

These results are new concerning Canada, the Eurozone, and the United Kingdom for the recent period, and raise two questions. The first relates to the potential exhaustion of advances in ICT performance. If this exhaustion materializes in the near future, it could result in the ebb of one of the key sources of productivity growth that took place over the past few decades. As a consequence, this could decrease medium and long term potential growth for the major advanced economies.

Chart 4
Contribution of ICT Capital Intensity to Labour Productivity Growth
(percentage points per year)



Source: Authors' calculations.

The second question relates to the lag in ICT diffusion from which Canada, the Eurozone, and the United Kingdom suffer in comparison with the United States. The literature shows that the lag can be explained, in particular for the Eurozone, by an lower share of workers with post-secondary education and especially by anticompetitive regulations, as well as labour and product market rigidities (Cette and Lopez, 2012). This signifies that ambitious structural reforms could contribute to a reduction of this gap. Consequently, this would allow the Eurozone to benefit from the greater advances in productivity introduced by a stronger diffusion of ICT. In the current period characterized by very weak growth in the Eurozone, this finding strongly suggests the need for a commitment to such ambitious reforms.

References

Aghion, Philippe, Philippe Askenazy, Renaud Bourlès, Gilbert Cette and Nicolas Dromel (2009) "Education, Market Rigidities and Growth," *Economics Letters*, Vol. 102, No.1, pp 62-65.

Aizcorbe, Ana, Stephen Oliner and Daniel Sichel (2008) "Shifting Trends in Semiconductor Prices and the Pace of Technological Progress," *Business Economics*, Vol. 43, No. 3, pp. 23-39.

Byrne, David, Stephen Oliner and Daniel Sichel (2013) "Is the Information Technology Revolution Over?" *International Productivity Monitor*, Number 25, Spring, pp. 20-36.

Cette, Gilbert (2014) "Does ICT Remain a Powerful Engine of Growth?" *Revue d'Economie Politique*, Vol. 124, No. 4, juillet-août, pp. 473-492.

Cette, Gilbert and Jimmy Lopez (2012) "ICT Demand Behaviour: An International Comparison," *Economics of Innovation and New Technology* Vol. 21, No. 4, pp. 397-410.

Cette, Gilbert, Jimmy Lopez and Jacques Mairesse (2013) "Upstream Product Market Regulations, ICT, R&D and Productivity," NBER Working Paper No. 19488, National Bureau of Economic Research, Cambridge, MA.

Cette, Gilbert, Yusuf Kocoglu, and Jacques Mairesse (2009) "Productivity Growth and Levels in France, Japan, the United Kingdom and the United States in the Twentieth Century," NBER Working Paper No. 15577, National Bureau of Economic Research, Cambridge, MA.

Colecchia, Alessandra, and Paul Schreyer (2001) "ICT Investment and Economic Growth in the 1990s: Is the United States a Unique Case?" OECD Science, Technology and Industry Working Papers 2001/07, OECD.

Gordon, Robert (2012) "Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds," NBER Working Paper No. 18315, National Bureau of Economic Research, Cambridge, MA.

Gordon, Robert (2013) "US Productivity Growth: the Slowdown has Returned after a Temporary Revival." *International Productivity Monitor*, Number 25, Spring, pp. 13-19.

Guerrieri, Paolo, Matteo Luciani, and Valentina Meliciani (2011) "The Determinants of Investment in Information and Communication Technologies," *Economics of Innovation and New Technology* Vol. 20, Number 4, pp. 387-403.

Jorgenson, Dale (1963) "Capital Theory and Investment Behavior," *American Economic Review*, Vol. 53, No. 2, pp. 247-259.

Jorgenson, Dale (2001) "Information Technology and the United States Economy," *American Economic Review*, Vol. 91, No. 1, pp. 1-32.

Jorgenson, Dale, Mun Ho, and Kevin Stiroh (2006) "Potential Growth of the US Economy: Will the Productivity Resurgence Continue?" *Business Economics*, Vol. 41, No. 1, pp. 7-16.

Pilat, Dirk, and Frank Lee (2001) "Productivity Growth in ICT-producing and ICT-using Industries: A Source of Growth Differentials in the OECD?" OECD Science, Technology and Industry Working Papers 2001/04, OECD.

Rai, Vikram and Andrew Sharpe (2013) "Can the Canada-US ICT Investment Gap be a Measurement Issue?" *International Productivity Monitor*, Number 26, Fall, pp. 63-85.

Schreyer, Paul (2000) "The Contribution of Information and Communication Technology to Output Growth: A Study on the G7 Countries," OECD Science, Technology and Industry Working Papers 2000/2, OECD.

Solow, Robert (1957) "Technical Change and Aggregate Production Function," *Review of Economics and Statistics* Vol. 39, No. 3, pp. 312-320.

Timmer, Marcel, Robert Inklaar, Mary O'Mahony, and Bart Van Ark (2011) "Productivity and Economic Growth in Europe: A Comparative Industry Perspective," *International Productivity Monitor* Number 21, Spring, pp. 3-23.

Van Ark, Bart, Mary O'Mahony, and Marcel Timmer (2008) "The Productivity Gap between Europe and the United States: Trends and Causes," *Journal of Economic Perspectives*, Vol. 22, No. 1, pp. 25-44.