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R&D and ICT Investment and GDP

A study of OECD countries

Bachelor's thesis within Economics

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Abstract

This thesis examines the contributions of R&D investment and ICT investment on economic wealth in OECD countries. The way to measure the economic wealth is domestic gross product (GDP). The theoretical framework is based on Solow aggregate production function, where the R&D and ICT are seen as sources of technological change. The regressions use a set of country cross-sectional panel data. The findings of this paper show that R&D investment contributes to GDP, and ICT investment as a part of R&D investment also contributes to GDP.

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1 Introduction

The growth of economic wealth can be achieved through various factors. The development of new technology is one of the major factors. In recent decades, many countries have witnessed strong growth driven by technological progress. It is claimed that economic growth is driven by technological changes which result from research and development (R&D) investments of profit maximizing agents (Romer, 1990). The R&D investment is a key leading indicator of technological changes, which lead to new knowledge, products, and processes. Thus, R&D leads to the improvements in the growth of economic wealth and standard of living (Link & Siegel, 2007).

Information and communication technology (ICT) investment is a vital dimension of R&D investment. OECD (2001) examined different sources of growth in OECD countries and found that neither increase of labour nor improved use of capital has been a single factor driven economic growth in all OECD countries (OECD, 2001). However, information and communication technology is a key factor behind economic development. Many policy makers are focusing on ICT in order to enhance long term economic growth. Schreyer (2000) points out that information and communication technology is an important thriving technology in the "new economy", and it plays a major role in the sustained growth of the "new economy". The "new economy" refers to the inflation-free growth economy with computerization and globalization. ICT and its applications contribute to economic growth and multi-factor productivity in recent years.

1.2 Problem

In the past few decades, we have witnessed the US economy revived in the 1980s result from large investment in R&D and ICT. Many scholars noted that economic growth can be achieved through technological progress; and technological progress can be achieved through R&D investment, since the R&D investment leads to new knowledge, inventions, and innovations. Now OECD countries are taking the R&D investment more seriously in order to boost economic performance and increase competitiveness. They found that the R&D investment generates knowledge spillovers and contributes to economic growth. Nowadays, the rapid diffusions of internet, broadband networks, and mobile telephony have caught the attention of many researchers. They claimed that the various use of ICT has influenced the relations of production and productivity. Many policy makers try to encourage the diffusion of ICT in order to increase competitiveness. An OECD study points out that there is a positive link between use of ICT and firm performance since ICT can make firms more competitive. Besides, ICT also plays a crucial role in knowledge intensive activities and process of globalization. However, an investigation by OECD states that the role of ICT in economic activities has been exaggerates by some studies. The questions capture attention is that if the ICT and R&D investments play the same story as in the US economy in the economic activities of OECD countries. Whether do R&D and ICT investments contribute to economic wealth in OECD countries or not?

1.3 Purpose

The purpose of this thesis is to analyze contribution of R&D investment and ICT investment to economic wealth. The paper uses GDP index to measure the economic wealth. It attempts to examine the economic impacts of R&D and ICT based on data for OECD countries, concentrating on the time period from 2003 to 2008. This paper regard ICT investment as an important part of R&D investment, and R&D investment is embodied in advancement of technology.

1.4 Previous Study

Many researchers have investigated the issue of R&D and ICT investment on economic output, and many of their works show that the investments in R&D and ICT contribute positively to output growth. Economic theories (Solow, 1957; Romer, 1990) state that technological change is the major source of productivity and output growth. Growth in the long run driven by technical progress arises endogenously through R&D investment. Romer (1990) and Grossman & Helpman (1991) illustrated a “scale effects” that if the resources devoted to R&D is doubled, then the per capital growth rate of output should also be double. The result from the R&D-based model discussed by Jones (1995) shows that the long-run per capita growth depends only on exogenous parameters, but independents on policy changes such as subsidies to R&D. Besides, the steady-growth also relies on the growth of inventions, which reflect the link innovations and scientists.

Whether does ICT contribute to economic growth and improvement of productivity has been a controversial issue in academia. Many of the literatures use the United States as a reference point to analyze the impact of ICT on economic growth and development. Some researchers stated that the input of ICT capital has no direct correlation with the productivity growth in the United States in the early 80s. (Baily, Gordon & Solow, 1981) And Oliner and Sichel (1994) also indicated that computers compose a relatively small share of the entire capital stock. However, they repudiate their early demonstrations in later works. Evidence from last ten years suggests that new technology (especially information and communication technology) has substantially contributed to the improvement of growth and productivity. Bloom, Draca, Kretschmer & Sadun (2007) found that ICT investment substantially improve the management practices and organization structure in public sectors. ICT is regarded as an important capital good in the capital stock by many researchers. Several studies (Jorgenson & Stiroh, 2000; Oliner &

Sichel, 2000) over the 1990s find a significant positive relation between information technology and MFP growth in the United States. Schreyer (2000) studied the contribution of ICT to output growth based on the G7 countries. He points out that the ICT capital goods are important contributors to economic growth and multi-factor productivity (MFP) growth though there is little evidence that they are inherently different from other capital goods. And ICT generates spillovers which exceed the direct returns to ICT capital.

1.5 Outline

The second section will present the theoretical framework. It shows the output growth accounting and provides two important models: R&D model and ICT model. Then it discusses the investment in R&D and ICT. The third section will show the data and regressions. The fourth section will discuss the econometric results. The fifth section which is the final section will give a conclusion of the thesis.

2 Theoretical Framework

2.1 Definitions

R&D defined

R&D is the abbreviation of the phrase research and development. According to OECD, it refers to creative work undertaken on a systematic basis in order to increase the stock of knowledge. R&D includes knowledge of humanity, culture and society, as well as the use of this stock of knowledge to devise new applications. R&D consists of three activities: basic research, applied research, and experimental development. Expenditure for research and development is a key indicator of private and government efforts to obtain competitive advantage in science and technology (OECD, 2008). R&D investment can benefit firm performance. Firms and corporations can achieve and sustain a competitive advantage through investment in R&D and adoption of new technology. From a national perspective, firms aggregate to industries, and industries aggregate to the whole economy. Therefore, investment in R&D can enhance economic productivity as a whole (Link & Siegel).

ICT defined

The word ICT was first used by Dennis Stevenson in his report to UK government. Information and communication technology (ICT) refers to all the technological means which used to handle information and aid communication. ICT consists of all information technology (IT) as well as telephony, broadcast media, audio, video processing, monitoring functions, and transmission and network based control, including computer hardware, computer software, network hardware, computer and communication services, and communication equipment (Stevenson, 1997). ICT is considered as a requirement for economic development and improvement of social conditions. The United Nations Development Programme (UNDP) denotes that lack of ICT contributes to the widening of the gap between developing countries and developed countries.

2.2 Accounting for Output Enhancement

The aggregate production function of Solow can provide the theoretical framework for the analysis. Moreover, Solow (1957) has developed an explicit model to assess the contribution of technological change to output growth. The production function hypothesize that the growth rate of output depends on the growth rate of capital (K) and labour (L) as well as the technological change. Mathematically, it can be expressed as:

$$Q = A(t)\ F(K, L) \qquad (1)$$

Where Q represents output and K and L represent capital and labour inputs in physical units respectively. The t represents time appears in F allow for technological change. The factor A (t) measures the cumulative effect of shifts over time. The production function (1) indicates the contribution of the growth of inputs and technological progress to output growth. And Solow assumed that the production function has a diminishing return with constant returns to scale respect to capital and labour.

The model was developed based on the United States economic growth from 1909 to 1949 due to the technological change. Solow (1957) concluded that "*Gross output per man hour doubled over the interval, with 87$^1/_2$ per cent of the increase attributable to technical change and the remaining 12$^1/_2$ per cent to increased use of capital*."

Solow illustrated the aggregate production function by using a Cobb-Douglas function:

$$Q = A(t)\ K^{\alpha}\ L^{\beta} \qquad (2)$$

The model above was hypothesized with perfect competition and constant return to scale. The α and β represent the shares of income distributed to capital and labour respectively. (α + β = 1)

R&D model:

Add the R&D investment to equation (2), and translate shift factor A(t) into constant C which represents all the technical change shift exclude R&D investment.

$$Q = C\ K^{\alpha}\ L^{\beta}\ R^{\gamma} \qquad (3)$$

Take the natural logarithm of both sides of equation (3):

$$\ln Q = \ln C + \alpha \ln K + \beta \ln L + \gamma \ln R \qquad (4)$$

In equation (4), C is a constant; it represents all the technical change shift exclude R&D investment. The α, β, and γ represent the elasticities of production of capital, labour, and R&D investment respectively. R represents the research and development expenditures. It refers to the expenditure on creative work undertaken to increase knowledge and the use of knowledge for new applications. (World Bank)

ICT model:

Add the ICT investment to equation (2), and translate shift factor A(t) into constant C which represents all the technical change shift exclude ICT investment.

$$Q = C\, K^{\alpha}\, L^{\beta}\, I^{\gamma} \qquad (5)$$

Take the natural logarithm of both sides of equation (5):

$$\ln Q = \ln C + \alpha \ln K + \beta \ln L + \gamma \ln I \qquad (6)$$

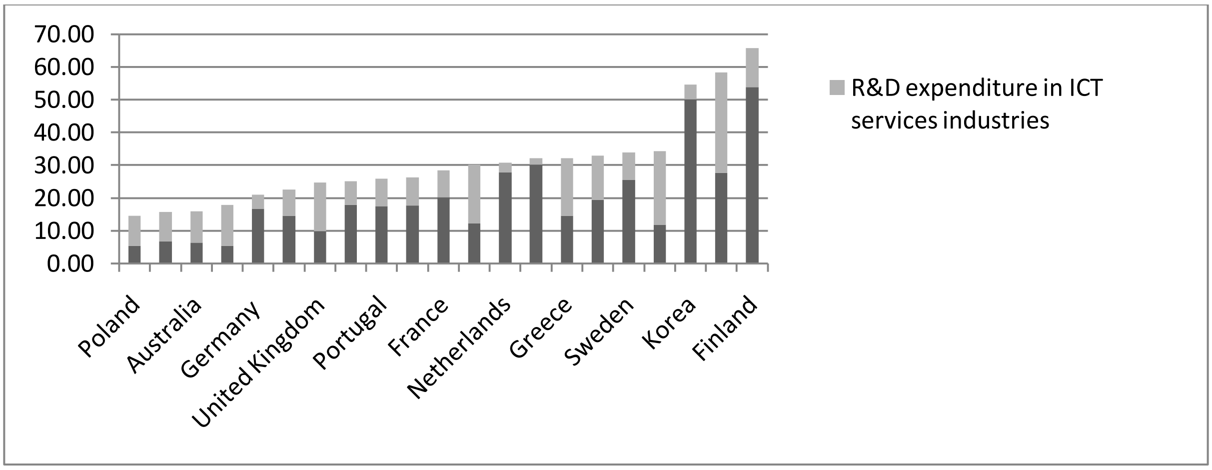
In equation (6), C is a constant; it represents all the technical change shift exclude ICT investment. The α, β, and γ represent the elasticities of production of capital, labour, and ICT investment respectively. I represents the information and communication technology expenditures. It includes the expenditures on computer hardware; computer software; computer services; communications services; and wired and wireless communications equipment. (The World Bank)

2.3 Discussion

R&D investment

R&D investment as a source of technological change has improved the multifactor productivity and economic growth in many OECD countries. Without any doubt, technical innovation is a major factor behind economic growth. The advancement of technology provides new products and process, which make the economic activities more productive. Many researchers claim that R&D has substantial contributions to firms and overall economic development. R&D investment in firms induces the firms with more competitive advantages, which can improve the performance of the firms. The growth in firms level can aggregate to the whole economies. R&D investment can stimulate economic growth and TFP (total factor productivity) growth directly through technology transfer and innovations. R&D also generates an important spillover at the world level from advanced countries to less advanced countries (Griffith, Redding & Reenen, 2004).

ICT investment is a particularly part of R&D expenditure in both public and private sectors. In recent years, more and more R&D expenditure has spent on the ICT industries, and the more spent, the more benefits it generates. Figure 1 shows the R&D expenditure in both ICT services industries and ICT manufacturing industries, and most R&D expenditure is spent on ICT manufacturing industries. The rate of R&D expenditure in the ICT industries is the highest in Finland in 2005. In Finland, the proportion of ICT goods in all export goods is nearly one fifth in 2004, which is the largest in the world. And Finland also has a remarkably high rate availability of qualified ICT engineers.

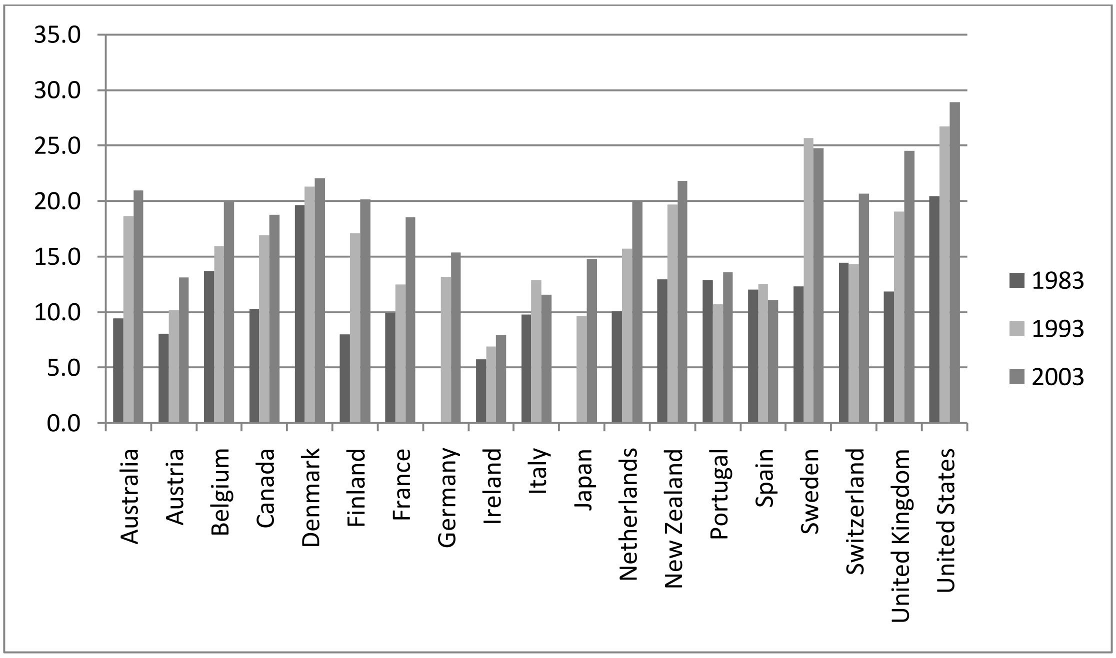


Source: OECD

Figure 1. R&D expenditure in selected ICT industries, 2005 (As a percentage of business enterprise sector R&D expenditure)

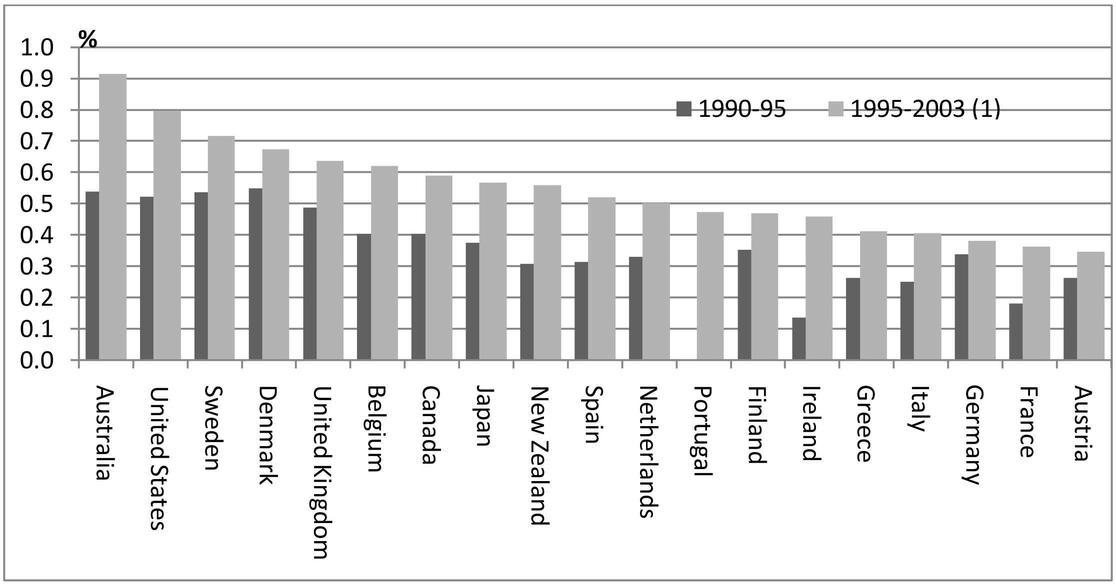
ICT investment

ICT investment is only a part of ICT products. In general, ICT investment is divided into IT equipment, communication equipment, and hardware and software. In 2000, ICT investment was accounted for almost one third of non-residential gross fixed capital formation in some OECD countries. Figure 2 shows that the average ICT investment in selected OECD countries as a share of gross fixed capital formation (GFCF) is approximately 11.85% in 1983, 15.77% in 1993, and 18.34% in 2003. It is continuously increasing though the two decades. The share of ICT investment of United States in 2003 is the highest among those 19 OECD countries, and the next top 5 is Sweden, United Kingdom, Denmark, New Zealand, and Australia. ICT investment contributes to GDP growth approximately 0.36 during the period 1990-1995 (Figure 3). The contribution of ICT investment increase significantly to 0.55 during the period 1995-2003. The contribution of ICT investment to GDP growth in Australia is particularly high in the second period, which is even higher than the United States, then followed by United States, Sweden, Denmark, and United Kingdom. ICT investment is remarkably high in United States and Sweden. In the past decades, ICT investment to a large extent boosts the US economy. Sweden has a strong economy which allows the early development of ICT. Now, Sweden is one of the developed countries with most advanced ICT with a sophisticated ICT market.



Source: OECD

Figure 2. ICT investment (As a percentage share of current prices ICT investment in total non-residential gross fixed capital formation)

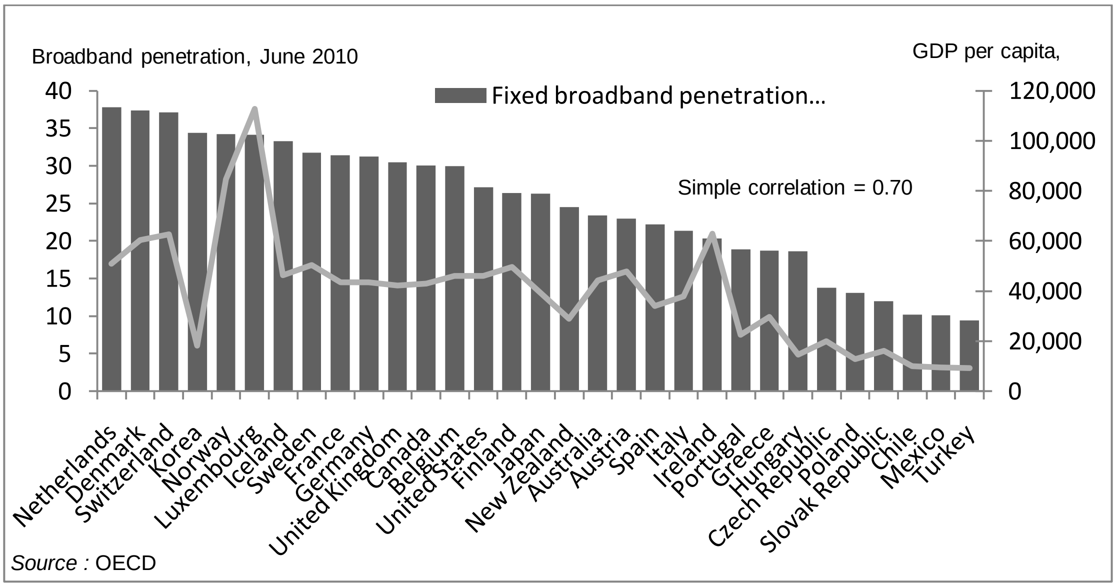


1. 1995-2002 for Australia, France, Japan, New Zealand and Spain.
Source: OECD

Figure 3. Contributions of ICT investment to GDP growth (In percentage points)

ICT application

The application of ICT is closely related to the contribution of ICT to economic growth over OECD countries, especially in United States, New Zealand, Australia, and Nordic countries. The applications of ICT establish the infrastructure and provide business for productive equipment and software. Nowadays, ICT has gone deeper into manufacturing industries, public and service sectors. Many ICT key indicators tend to indicate that high rate of ICT applications lead to high economic output. Figure 4 points out that the use of ICT is highly correlated to GDP per capita growth, since correlation of broadband penetration and GDP per capita is 0.7. It indicates that applications of ICT contribute to GDP per capita growth in OECD countries.



Source: OECD

Figure 4. Broadband penetration and GDP per capita

Impact of ICT

ICT has impact on the success of firms and the economic performance. One of the most important impacts of ICT is that ICT investment contributes to GDP growth. In the 1990s, the rapid prices falling induced large investment in ICT hardware and software. The rapid innovation of the ICT products increases the multi-factor productivity growth. And the ICT investment contributes to economic growth in several OECD countries. The table 1 below shows the contributions of ICT investment to GDP growth in selected OECD countries. ICT investment plays a very important role to GDP growth, more than 0.5 percent in Australia, United States, Sweden, and Denmark from 1990 to 1995. From 1995 to 2003, the top five countries have remained their ranks, and the percentage of ICT contribution to GDP growth in Australia is particularly high, almost 1 percent. During the period 1995 to 2003, the contributions of ICT investment to GDP growth in the selected countries have all increased with an approximate 0.6 percent growth rate on average. The reason for differences of impacts on GDP in different OECD countries could be the different scales of economy and different population and labour force. Another important impact of ICT is that it plays a crucial role in the knowledge intensive and globalization intensive activities at firms-level. ICT can support and facilitate innovations in the firms. Besides, ICT can also lower communication cost and shorter the communication time. as a result, it makes firms more efficient and competitive.

Table 1. Contributions of ICT investment to GDP growth, 1990-95 and 1995-2003 (1), in percentage points

	1990-95	1995-2003 (1)
Australia	0.539	0.915
United States	0.523	0.796
Sweden	0.537	0.717
Denmark	0.549	0.647
United Kingdom	0.488	0.637
Belgium	0.403	0.620
Canada	0.403	0.589
Japan	0.374	0.568
New Zealand	0.308	0.560
Spain	0.314	0.520
Netherlands	0.329	0.501
Finland	0.325	0.468
Ireland	0.136	0.458
Greece	0.263	0.412
Italy	0.251	0.405
Germany	0.338	0.381
France	0.180	0.362
Austria	0.263	0.347

1. 1995-2002 for Australia, France, Japan, New Zealand and Spain

Source: OECD Productivity Database, September 2005

3 Empirical Analysis

3.1 Data

The data in the regressions are collected from the World Bank database. The data is a set of panel data of OECD countries. In regression 2, the time period is chosen from 2003 to 2008; and the sample of countries chosen comprises 29 OECD countries cross-sections, including Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States. In other regressions, the time period is chosen from 2003 to 2007; and the sample of countries chosen comprises 23 OECD countries cross-sections, which is the same as in regression 2 except Australia, Chile, Italy, Mexico, New Zealand, and Switzerland.

In the following models, Y represents the gross domestic product (GDP) in current US dollars. It refers to the market value of all the final goods and services produced within a country in a given period. K represents the gross capital formation in current US dollars. The gross capital formation is the total investment within a country in a given period. L represents the total labour force. Total labor force refers to people age 15 and above, and meets the International Labour Organization definition: all people who supply labour for the production of goods and services during a given period. The total labour force includes both employed and unemployed people, but excludes the homemakers and other unpaid workers. R represents the Research and development expenditure in current US dollars. It refers to the expenditures on creative work undertaken to increase knowledge and the use of knowledge for new applications. And I represents the information and communications technology expenditures in current US dollars. Information and communications technology expenditures include computer hardware; computer software; computer services; communications services; and wired and wireless communications equipment. (The World Bank)

3.2 Regression Models

The regression models are based on the R&D model (equation 4.1) and ICT model (equation 4.2) in theoretical framework. The regression 1 and regression 2 are aim to test whether R&D investment and ICT investment contribute to domestic gross product respectively. Since the regression 1 and 2 test the contributions R&D and ICT investments to GDP separately, thus it is necessary to test the R&D and ICT investment together. In regression 3, R&D investment and ICT investment are both included in the model together. In regression 4, an interaction variable is included in the model and R&D investment and ICT investment are excluded from the model. The interaction equals to the R&D investment multiply the ICT investment. This aims to test the contribution of R&D and ICT investment to GDP together.

Regression 1: model with R&D investment

$$\ln Y_t = C + \alpha \ln L_t + \beta \ln K_{t-1} + \gamma \ln R_{t-1}$$

This model runs with one year lag for gross capital formation and R&D investment. The adjusted sample period is from 2004 to 2007.

The hypothesis of the regression 1 is that the R&D investment contributes to economic wealth. The null hypothesis H_O: $\gamma = 0$ is the R&D investment does not contribute to GDP and the alternative hypothesis H_A: $\gamma \neq 0$ is the R&D investment contributes to GDP. The hypothesis is tested at 5% significant level.

Regression 2: model with ICT investment

$$\ln Y_t = C + \alpha \ln L_t + \beta \ln K_{t-1} + \gamma \ln I_{t-1}$$

This model runs with one year lag for gross capital formation and ICT investment. The adjusted sample period is from 2004 to 2008.

The hypothesis of the regression 2 is that the ICT investment contributes to economic wealth. The null hypothesis H_O: $\gamma = 0$ is the ICT investment does not contribute to GDP and the alternative hypothesis H_A: $\gamma \neq 0$ is the ICT investment contributes to GDP. The hypothesis is tested at 5% significant level.

Regression 3: model with R&D and ICT investment

$$\ln Y_t = C + \alpha \ln L_t + \beta \ln K_{t-1} + \gamma \ln R_{t-1} + \sigma \ln I_{t-1}$$

This model runs with one year lag for gross capital formation, ICT investment and R&D investment. The adjusted sample period is from 2004 to 2007.

The hypothesis of the regression 3 is that the R&D and ICT investments both contribute to economic wealth. The null hypothesis H_O: $\gamma=\sigma= 0$ is the R&D and ICT investments do not contribute to GDP and the alternative hypothesis H_A: γ and σ are not equal to zero is the R&D and ICT investments contribute to GDP. The hypothesis is tested at 5% significant level.

Regression 4: model with interaction

$$\ln Y_t = C + \alpha \ln L_t + \beta \ln K_{t-1} + \gamma \ln \text{Interaction}_{t-1}$$

This regression runs with one year lag for gross capital formation and the interaction. The interaction = R&D investment × ICT investment. The adjusted sample period is from 2004 to 2007.

The hypothesis of the regression 4 is that the interaction contributes to economic wealth. The null hypothesis H_O: $\gamma = 0$ is the interaction does not contribute to GDP and the alternative hypothesis H_A: $\gamma \neq 0$ is the interaction contributes to GDP. The hypothesis is tested at 5% significant level.

4 Assessment of Empirical Results

4.1 Econometric Results

The results of the four regressions are presented below (Table 2). All the results data are shown two decimal places. The numbers in the table without brackets are t-values and the numbers with brackets are p-values.

Table 2. Econometric results

	Regression 1	**Regression 2**	**Regression 3**	**Regression 4**
Dependent variable	GDP	GDP	GDP	GDP
C	3.48*	2.33*	3.48*	3.15*
	(0.00)	(0.00)	(0.00)	(0.00)
L	0.14*	0.05*	0.14*	0.10*
	(0.00)	(0.04)	(0.01)	(0.00)
K	0.71*	0.72*	0.71*	0.69*
	(0.00)	(0.00)	(0.00)	(0.00)
R&D	0.14*		0.14*	
	(0.00)		(0.00)	
ICT		0.24*	0.03	
		(0.00)	(0.98)	
Interaction				0.10*
				(0.00)
Total panel observations	92	145	92	92
R^2	0.99	0.97	0.99	0.99

*. Regression is significant at the 0.05 level (2-tailed).

Result from Regression 1

The result of regression 1 shows the coefficient of R&D variable is positive. The P-value of R&D variable is less than 0.05, thus reject the null hypothesis at 5% significant level. Therefore, we can conclude that the R&D investment contributes to economic wealth which measured by GDP.

Result from Regression 2

The result of regression 2 shows that the coefficient of ICT variable is positive. The P-value of ICT variable is less than 0.05, thus reject the null hypothesis at 5% significant level. Therefore, we can conclude that the ICT investment contributes to economic wealth which measured by GDP.

Result from Regression 3

The result of regression 3 shows that the coefficients of R&D and ICT variables are positive. The R&D variable is significant at 0.05 level; whereas the ICT variable is insignificant at 0.05 level. Thus do not reject the null hypothesis. It indicates that R&D investment contributes to economic wealth, but the ICT investment does not contribute to economic wealth. However, it results in multicollinearity since the ICT investment is a part of R&D investment.

Result from Regression 4

The result of regression 4 shows the coefficient of interaction variable is positive. The P-value of interaction variable is less than 0.05, thus reject the null hypothesis at 5% significant level. Therefore, we can conclude that the R&D investment and ICT investment have effect on each other and they contributes to economic wealth which measured by GDP.

4.2 Further Assessment of Regression Results

From the results of regressions 1 and 2, they all indicate that the R&D investment and ICT investment contribute to economic wealth individually. The result of regression 1 shows that the coefficient of R&D variable $\gamma = 0.14$, it shows that the elasticity of production of R&D investment is 0.14. Therefore, all else equal, if we increase R&D investment by one percent, GDP will on average increase by 0.14 percent. The result of regression 2 shows that the coefficient of ICT variable $\gamma = 0.24$, it shows that the elasticity of production of ICT investment is 0.24. Therefore, all else equal, if we increase ICT investment by one percent, GDP will on average increase by 0.24 percent. In regression 2, the coefficient of ICT investment is larger than the coefficient of R&D investment in regression1, however, it does not mean that the ICT investment has larger contribution to GDP than R&D investment. Because the ICT investment is a component in R&D investment, and they have different scales. Thus, it cannot conclude that the ICT investment has larger contribution to GDP than R&D investment. In order to analyze the differences of the contributions of R&D investment and ICT investment individually, a comparison of regression 1 and regression 2 is conducted(Table 3). The regression 3 includes both R&D and ICT variables. However the result shows that the ICT variable is insignificant at 0.05 level, which means that the ICT investment does not contribute to GDP when the R&D investment is included. In order to discover the relation of R&D and ICT and their effects on each other and GDP, the regression 4 is conducted. Table 4 shows the comparison of regression3 and 4.

Table 3. Compare regression 1 and 2

	Regression 1	**Regression 2**
Dependent variable	GDP	GDP
C	3.48*	2.33*
	(0.00)	(0.00)
L	0.14*	0.05*
	(0.00)	(0.04)
K	0.71*	0.72*
	(0.00)	(0.00)
R&D	0.14*	
	(0.00)	
ICT		0.24*
		(0.00)
R^2	0.99	0.97

*. Regression is significant at the 0.05 level (2-tailed).

From the comparison table above (Table 3), the dependent variable of the two regressions is annually domestic gross production (GDP). Their explanatory variables both include labour and capital, but regression 1 with a R&D investment variable, and regression 2 with an ICT investment variable. The coefficients of R&D and ICT variables are 0.14 and 0.24 respectively, and they are both significant at 0.05 level. From the R&D model, it can conclude that all else equal, if R&D investment increase by one percent, GDP will on average increase by 0.14 percent. From the ICT model, it can conclude that all else equal, if ICT investment increase by one percent, GDP will on average increase by 0.24 percent. Since the ICT investment is a part of R&D investment, and they have different scales, it cannot conclude that ICT investment contributes more to GDP than R&D investment. The R^2s for the two models are 0.99 and 0.97 respectively, which means that the two regression models fit the data very well.

Table 4. Compare regression 3 and 4

	Regression 3	**Regression 4**
Dependent variable	GDP	GDP
C	3.48*	3.15*
	(0.00)	(0.00)
L	0.14*	0.10*
	(0.01)	(0.00)
K	0.71*	0.69*
	(0.00)	(0.00)
R&D	0.14*	
	(0.00)	
ICT	0.03	
	(0.98)	
Interaction		0.10*
		(0.00)
R^2	0.99	0.99

*. Regression is significant at the 0.05 level (2-tailed).

From the comparison table above (Table 4), the dependent variable of the two regressions is annually domestic gross production (GDP). Their explanatory variables both include labour and capital. However, in regression 3, the R&D investment and ICT investment are included at the same time. In regression 4, R&D investment and ICT investment are excluded, instead the interaction term is included. The interaction equals to the R&D investment multiply the ICT investment. It measures the interactive effect of R&D investment together with the ICT investment. In regression 3, the ICT variable has a positive sign, but the coefficient is insignificant at 0.05 level. Although the t-statistic is insignificant, the R^2 is still very high. It is because that they result in multicollinearity, since ICT investment and R&D investment are correlated. ICT investment is a crucial dimension of R&D investment, and they convey the similar information. According to the correlations (Table 5), the correlation of ICT investment and R&D investment is 0.99; it indicates that they are highly correlated. The multicollinearity in the model makes the precise estimation difficult. In regression 4, the interaction variable has a positive sign and the coefficient is significant at 0.05 level. It indicates that R&D investment and ICT investment have effect on each other, and ICT investment varies with the R&D investment. And R&D and ICT investments have a positive interactive effect on economic wealth. Since the R^2 is 0.99, it means that the regression model fits the data very well.

Table 5. Correlations of R&D and ICT

Pearson Correlation	0.99**
Sig. (2-tailed)	0.00
N	115

**. Correlation is significant at the 0.01 level (2-tailed).

5. Conclusion and Suggestions

Based on the findings of the thesis, it can conclude that the R&D and ICT investment in OECD countries both contribute to economic wealth which measured by GDP. Besides, the R&D investment and ICT investment are highly correlated and have effects on each other. This study takes ICT investment as a crucial component of R&D investment. R&D and ICT investment are regarded as a source of technological change, and the technological change contributes to economic wealth.

For the suggestions, the policy makers can pay more attention to R&D and ICT investment and take it more seriously in order to increase the economic wealth. Government can improve the research and development infrastructures at the public R&D department or organizations. The government's R&D investment in education is also with a great importance, since engineers and scientists are the main actor in the research and development process. Government can also promulgate effective policies to create a supportive climate for business innovation and encourage firms investing more in research and development. By encourage firms to invest more in research and development, government can make policies which can reduce the R&D costs and fees. For instance, government can decrease the taxation level on firms when investing more in R&D. And government can provide special funds and loans for firms to invest in R&D. Nowadays, the information and communication technology plays a more and more important role in the economic activities. And these technologies are transforming the economy and society. ICT makes firms and the whole economy more effective and competitive. The investment in ICT infrastructures by government, such as broadband and wireless, are very crucial. It provides firms and business with productive equipment. Besides, government should encourage firms to adopt new ICT in order to improve the performance of firms. The R&D investment and ICT investment have impact on each other. Government can give bonus to firms with large R&D investment which includes a large proportion of ICT investment. The growth and development of firms which result from the policies can also accumulated to the economic wealth.

5.2 Further Studies

For further studies, it would be interested to investigate the impacts of ICT investment in developing countries. The diffusion of ICT in developing countries has attracted many scholars' interest. The adoption of ICT could help the developing countries with the economy, health, education, social, and environment problems. And the impacts of ICT investment in developing countries could be different from the impacts in OECD countries. Therefore, it is would be worthwhile to study.

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Appendix

Regression 1:

Dependent Variable: LOG(Y)

Method: Panel Least Squares

Date: 04/28/11 Time: 19:12

Sample (adjusted): 2004 2007

Periods included: 4

Cross-sections included: 23

Total panel (balanced) observations: 92

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.484779	0.528932	6.588330	0.0000
LOG(L)	0.136826	0.035163	3.891241	0.0002
LOG(K(-1))	0.710598	0.061448	11.56422	0.0000
LOG(R(-1))	0.144861	0.030557	4.740717	0.0000

R-squared	0.987039	Mean dependent var	27.04470
Adjusted R-squared	0.986598	S.D. dependent var	1.274995
S.E. of regression	0.147605	Akaike info criterion	-0.946051
Sum squared resid	1.917274	Schwarz criterion	-0.836408
Log likelihood	47.51834	Hannan-Quinn criter.	-0.901798
F-statistic	2233.932	Durbin-Watson stat	0.238232
Prob(F-statistic)	0.000000		

Regression 2:

Dependent Variable: LOG(Y)

Method: Panel Least Squares

Date: 03/28/11 Time: 14:55

Sample (adjusted): 2004 2008

Periods included: 5

Cross-sections included: 29

Total panel (balanced) observations: 145

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.327703	0.298020	7.810557	0.0000
LOG(L)	0.045687	0.022034	2.073525	0.0399
LOG(K(-1))	0.715354	0.054835	13.04557	0.0000
LOG(I(-1))	0.239902	0.049727	4.824408	0.0000

R-squared	0.986304	Mean dependent var	27.04395
Adjusted R-squared	0.986012	S.D. dependent var	1.223244
S.E. of regression	0.144673	Akaike info criterion	-1.001479
Sum squared resid	2.951180	Schwarz criterion	-0.919362
Log likelihood	76.60723	Hannan-Quinn criter.	-0.968112
F-statistic	3384.551	Durbin-Watson stat	0.374506
Prob(F-statistic)	0.000000		

Regression 3:

Dependent Variable: LOG(Y)

Method: Panel Least Squares

Date: 04/01/11 Time: 09:59

Sample (adjusted): 2004 2007

Periods included: 4

Cross-sections included: 23

Total panel (balanced) observations: 92

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.477685	0.584210	5.952795	0.0000
LOG(L)	0.135907	0.047222	2.878062	0.0050
LOG(K(-1))	0.709547	0.071401	9.937436	0.0000
LOG(R(-1))	0.143836	0.046501	3.093196	0.0027
LOG(I(-1))	0.002980	0.101444	0.029376	0.9766

R-squared	0.987040	Mean dependent var	27.04470
Adjusted R-squared	0.986444	S.D. dependent var	1.274995
S.E. of regression	0.148450	Akaike info criterion	-0.924322
Sum squared resid	1.917255	Schwarz criterion	-0.787268
Log likelihood	47.51879	Hannan-Quinn criter.	-0.869006
F-statistic	1656.426	Durbin-Watson stat	0.238261
Prob(F-statistic)	0.000000		

Regression 4:

Dependent Variable: LOG(Y)

Method: Panel Least Squares

Date: 04/14/11   Time: 12:01

Sample (adjusted): 2004 2007

Periods included: 4

Cross-sections included: 23

Total panel (balanced) observations: 92

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.152488	0.487059	6.472497	0.0000

LOG(L)	0.100994	0.032094	3.146797	0.0023
LOG(K(-1))	0.686569	0.067669	10.14595	0.0000
LOG(INTERACTION(-1))	0.102716	0.022308	4.604411	0.0000

R-squared	0.986888	Mean dependent var	27.04470
Adjusted R-squared	0.986441	S.D. dependent var	1.274995
S.E. of regression	0.148463	Akaike info criterion	-0.934454
Sum squared resid	1.939638	Schwarz criterion	-0.824811
Log likelihood	46.98486	Hannan-Quinn criter.	-0.890201
F-statistic	2207.836	Durbin-Watson stat	0.241217
Prob(F-statistic)	0.000000		

Correlations：

		ICT	RD
ICT	Pearson Correlation	**1**	**,992****
	Sig. (2-tailed)		**,000**
	N	**115**	**115**
RD	Pearson Correlation	**,992****	**1**
	Sig. (2-tailed)	**,000**	
	N	**115**	**115**

**. Correlation is significant at the 0.01 level (2-tailed).